A LABORATORY COURSE IN PHYSICS OF THE HOUSEHOLD

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A LABORATORY COURSE

IN

PHYSICS OF THE HOUSEHOLD

TO ACCOMPANY

LYNDE'S PHYSICS OF THE HOUSEHOLD

BY

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PREFACE

THIS Laboratory Course in Physics of the Household covers the ground recommended by the College Entrance Board. It differs from similar courses in four ways: first, it contains Exercises in addition to the usual Experiments; second, it requires the use of the common weights and measures side by side with the metric weights and measures; third, it permits the use of much apparatus familiar to the student; and fourth, it encourages the student to set up a laboratory in his own home.

The Exercises help the student to appreciate how physics is applied in his home and in his environment in general. The Exercises and Experiments together complement the classroom work.

The use of the common weights and measures in addition to the metric weights and measures is justified, in the writer's opinion, as follows. Since we require young students to take a laboratory course in physics in order that they may obtain knowledge which they will apply in everyday life, it seems wise to allow them to obtain this knowledge in terms of the units (foot, pound, B.T.U., etc.) which they *must* use when they so apply it. Furthermore, the writer, although a strong advocate of the metric system, believes that it is pedagogically unsound to try to teach physics by means of the metric system exclusively. It is an attempt to teach an unknown subject by means of an unknown system of weights and measures and it leads to confusion and lack of power on the part of the student. Long experience leads the writer to believe that the correct method is to introduce the subject by means of the common system and then to use the two systems side by side. This is the method followed in this book.

There are three reasons why familiar apparatus (3-qt. pail, spring balance, common thermometer, etc.) is used. If the student uses apparatus with which he is familiar, he finds that he can make experiments at home and he learns that an experiment may be made when and where information is desired; whereas, if he uses only the apparatus commonly found in a school, he is likely to get the impression that an experiment is something to be made only in the school laboratory. The familiar apparatus, moreover, allows a student to work with large quantities and thereby decreases the chances of error. Also the familiar apparatus is cheap and easy to obtain.

The reason for encouraging the student to set up a laboratory at home is obvious. If he plans his own experiments on a given subject and then makes these experiments, he gets a firmer grasp of the subject than if he makes only the experiments in school.

The apparatus required for these experiments (except for a few in electricity) is simple and inexpensive and much of it is similar to that now found in high school laboratories. It is advisable to have one set for each two students in order that the whole class may make the same experiment at the same time. Where only one or two sets can be purchased, however, the class may make the experiments in rotation.

For the convenience of those ordering apparatus, we give on pages 139–146 a list of the apparatus required, with the approximate cost, and also the names and addresses of a number of firms from which the apparatus may be purchased. The prices quoted are those in effect before the war. The present prices can be obtained by writing to any of the firms mentioned.

C. J. L.

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TO THE STUDENTS

Many of you who take this course will wish you could make experiments at home. To help you to do this we list on pages 143–145 and illustrate in Figs. 1, 2, 3 and 4 below, the apparatus needed for a home laboratory. With this equipment you can perform, in whole or in part, more than two thirds of the experiments outlined in this book and many experiments of your own.

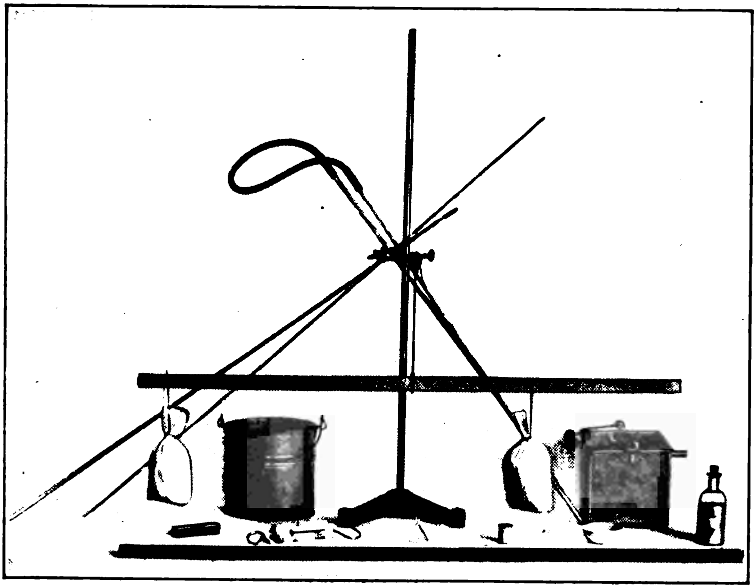

Fig. 1. Apparatus for a student's home laboratory in Mechanics.

The apparatus needed for a home laboratory in Mechanics is illustrated in Fig. 1 (except four single pulleys) and listed on page

143. With this equipment you can make, in whole or in part, experiments 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. You will need to find at home, some cord, a piece of rock, a piece of iron (an old flatiron will do), and a quart bottle.

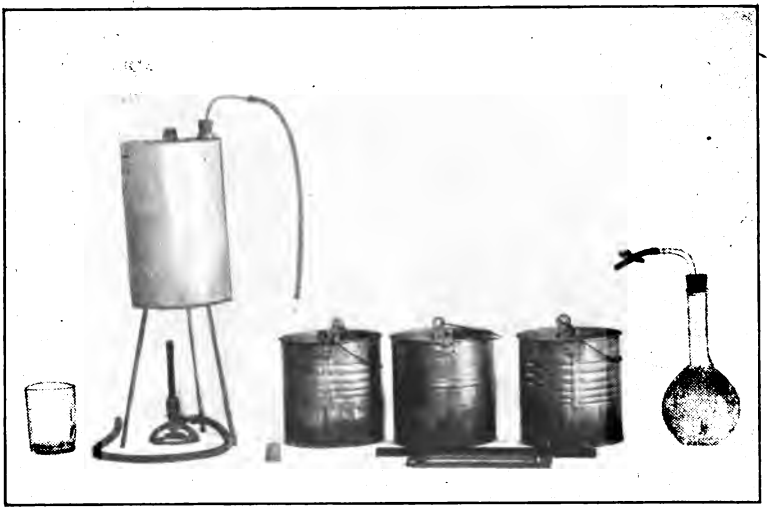

FIG. 2. Additional apparatus for a student's laboratory in Heat.

The additional apparatus required for a home laboratory in Heat is illustrated in Fig. 2 and listed on page 144; with this you can make, in whole or in part, experiments 12, 14, 15, 16, 17, 18, 19, 20. If gas is not available, you can use, as a source of heat, an alcohol stove, an oil stove, or the kitchen range.

The apparatus needed for a home laboratory in Electricity and Magnetism is illustrated in Fig. 3 and listed on page 144; with this you can make, in whole or in part, experiments 21, 22, 23, 24, 25, 26, 27. You will need also the supplies listed on page 145.

The apparatus for a home laboratory in Light and Sound is illustrated in Fig. 4, and listed on page 145; with this you can make, in whole or in part, experiments 34, 35, 36, 37, 38, 39, 40, 41, 45.

FIG. 3. Apparatus for a student's home laboratory in Electricity and Magnetism.

With the pendulum bob listed on page 145 and with apparatus listed under Mechanics you can make experiments 47, 48, 49, in Advanced Mechanics.

You will need at home a table on which to make the experiments, and a towel to dry the apparatus.

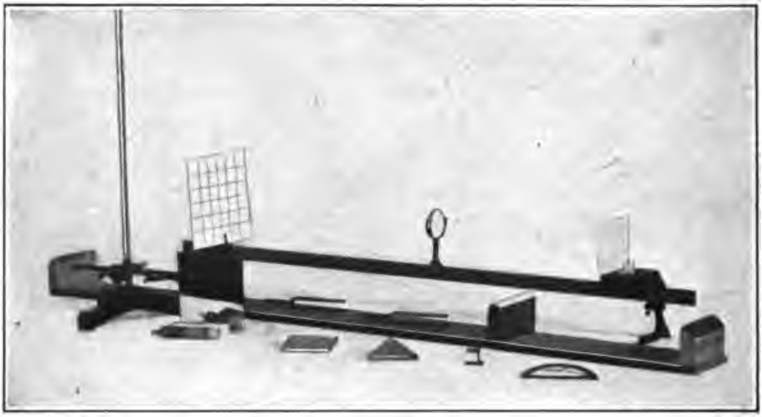

FIG. 4. Apparatus for a student's home laboratory in Light and Sound.

You will find that the most satisfactory way to make your own experiments is to think them out before you start and to put them down on paper somewhat as follows:

1. Outline the experiment you intend to make.
2. Make a rough drawing showing how you intend to arrange the apparatus.
3. State the results you expect to obtain.

When you have planned your work as above, make the experiment and compare the results you obtain with those you expected to obtain. Follow this plan with each experiment.

You will get a great deal of pleasure out of this work at home because you will find it very exhilarating to make experiments of your own; you will get a great deal of profit also because when you have planned and made experiments of your own on a given subject, you will find that you know it in a way you never could simply by making the experiments in school.

The prices quoted are those in effect before the war. You can get the present prices by writing to one of the firms listed on page 146. If the cost is too great for one student, a number might club together to buy the apparatus or at least part of it.

C. J. L.

A LABORATORY COURSE IN PHYSICS OF THE HOUSEHOLD

MECHANICS

Experiment 1. Levers of the first class.

To illustrate the lever law by means of a lever of the first class.

Yard stick.	Two 1 lb. weights.[1]
Support.	Meter stick.
One 2 lb. weight.[1]	Four 100 g. weights.

The lever law is: *A lever is balanced when the total moment on one side of the fulcrum is equal to the total moment on the other.* The moment of a weight is found by multiplying the weight by its distance from the fulcrum.

Method 1. Balance a yard stick, as shown in Fig. 5, until it remains horizontal. Note carefully the exact position of the fulcrum and make all measurements from this point.

Make the four experiments outlined below and two or three of your own. In each case, use the lever law to calculate the distance you expect to find. Then make the experiment and notice whether the distance found by experiment agrees with that found by calculation.

[1] Convenient weights of 1 lb., 2 lb., etc., can be made by filling cotton bags with sand or shot to the proper weight.

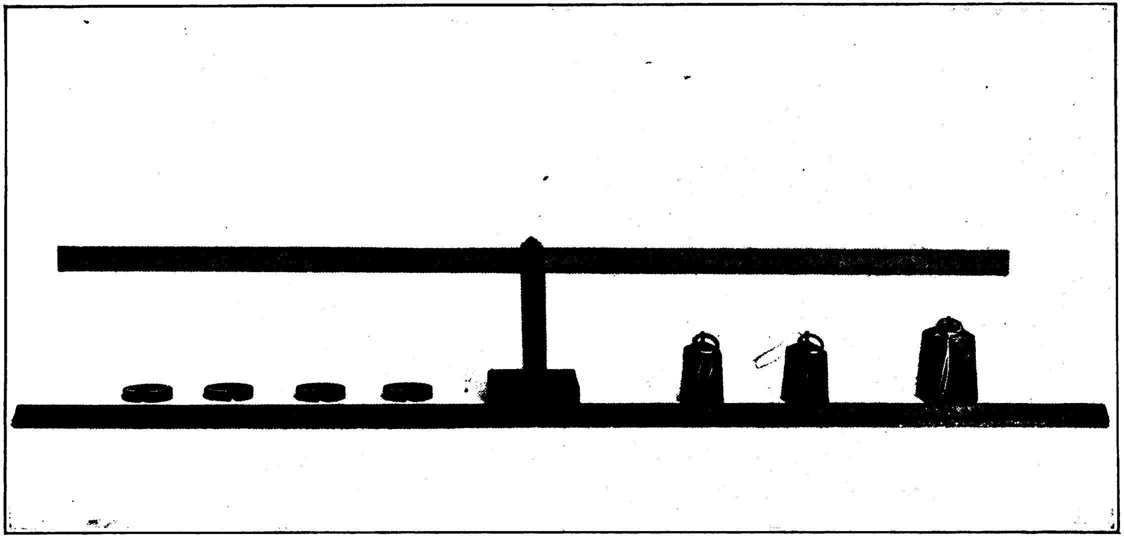

Fig. 5. Apparatus used to illustrate levers of the first class.

Weight	Distance from Fulcrum		Weight	Distance from Fulcrum	
				By calculation	By experiment
1 lb.	16 in.	balances	1 lb.		
1 lb.	16 in.	balances	2 lb.		
1 lb.	15 in.	balances	3 lb.		
1 lb.	6 in.	balance	2 lb.		
1 lb.	12 in.				

Method 2. Balance a meter stick. Make the four experiments outlined below and two or three of your own.

Weight	Distance from Fulcrum		Weight	Distance from Fulcrum	
				By calculation	By experiment
100 g.	40 cm.	balances	100 g.		
100 g.	40 cm.	balances	200 g.		
100 g.	45 cm.	balances	300 g.		
100 g.	20 cm.	balance	200 g.		
100 g.	40 cm.				

Does the lever law hold in each case; that is, is the total moment on one side of the fulcrum always equal to the total moment on the other side when the lever balances?

Experiment 2. Levers of the second and third class.

To illustrate the lever law by means of levers of the second and third class.

Yard stick.	One 1 lb. weight.
Spring balance with reading in ounces and grams.	One 2 lb. weight.
Block.	Meter stick.
Support.	Two 100 g. weights.
	One 500 g. weight.

Method. **Levers of the second class.** (1) Support a *yard* stick as shown in Fig. 6. One end, the fulcrum, rests on a block;

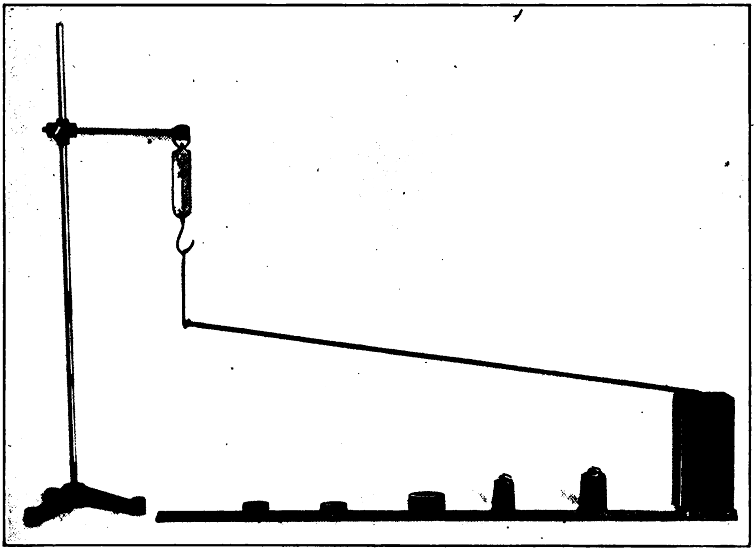

FIG. 6. Apparatus used to illustrate levers of the second class.

the other end is supported by a cord attached to a spring balance with a scale, divided into ounces. In all cases make the fulcrum the end at which the numbers on the yard stick begin.

Find the force recorded on the balance[1] when there are no weights on the lever, that is, the force required to support one end of the yard stick. Subtract this amount from all readings of the balance.

Make the three experiments given below and two of your own. In each case, use the lever law to calculate the force you expect to find. Then find the force by experiment.

Weight	Distance from Fulcrum		Force		Distance from Fulcrum
			By calculation	By experiment	
1 lb.	18 in.	is balanced by			36 in.
2 lb.	18 in.	is balanced by			36 in.
3 lb.	12 in.	is balanced by			36 in.

(2) Support a *meter* stick as shown in the illustration. Find the force in grams required to support one end of the meter stick when there are no weights on it. Subtract this amount from all readings of the balance.

Make the three experiments given below and two of your own. In each case find the force in grams, first by calculation, and then by experiment.

Weight	Distance from Fulcrum		Force		Distance from Fulcrum
			By calculation	By experiment	
200 g.	50 cm.	is balanced by			100 cm.
200 g.	75 cm.	is balanced by			100 cm.
500 g.	40 cm.	is balanced by			100 cm.

[1] If the end of the pointer of the spring balance is blunt, it is necessary to find a point on the end from which to make your readings. Do this as follows : Suspend the balance without weights and notice the point opposite the zero line. Make all subsequent readings from this point.

Method. **Levers of the third class.** (1) Support a *yard* stick as shown in Fig. 7. One end, the fulcrum, is held down by hand; the weight is attached near the other end, and a spring balance exerts a force upwards at some point between.

NOTE.—Hold the fulcrum down with one finger exactly at the end of the lever, but do not bear down on the balance.

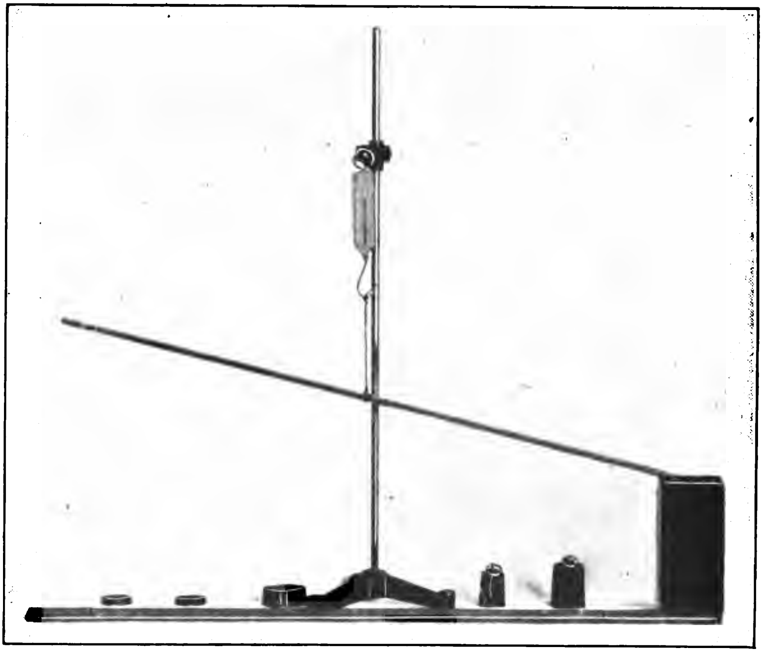

FIG. 7. Apparatus used to illustrate levers of the third class.

Find the force in ounces required to support the yard stick when there are no weights on it. Subtract this amount from all readings of the balance. Make the two experiments given below and one of your own. In each case use the lever law to calculate the force in ounces you expect to find, then find it by experiment.

Weight	Distance from Fulcrum		Force		Distance from Fulcrum
			By calculation	By experiment	
1 lb.	36 in.	is balanced by			18 in.
2 lb.	27 in.	is balanced by			18 in.

(2) Support a *meter* stick as shown in Fig. 7. Find the force in grams required to support the meter stick when there are no weights on it. Subtract this amount from each reading on the balance. Make the two experiments given below and one of your own. In each case, find the force in grams, first by calculation and then by experiment.

Weight	Distance from Fulcrum		Force		Distance from Fulcrum
			By calculation	By experiment	
200 g.	75 cm.	is balanced by			50 cm.
500 g.	80 cm.	is balanced by			50 cm.

Does the lever law hold in each case, that is, is the total moment upward always equal to the total moment downward when the lever is balanced?

Exercise 1. Lever Appliances.

Measure the force arm and weight arm of at least five of the following lever appliances and calculate the advantage of each: tack lifter, scissors, can opener, nutcracker, potato ricer, knife, fork, spoon, broom, fire tongs, sugar tongs.

Make a rough sketch of each appliance and mark on it the force arm, weight arm, advantage, and the lever class to which it belongs.

Measure the force arm and weight arm of at least four of the following wheel and axle appliances: grate shaker, wringer, coffee mill, ice-cream freezer, bread mixer, cake mixer.

Make a diagram of each and mark on it the force arm, weight arm, and advantage.

Home Exercise.

Repeat this exercise with at least three lever appliances and two wheel and axle appliances in your home.

Make a written report on this work.

Experiment 3. Pulleys.

To verify the law of the pulleys.

Four single pulleys.	One 2 lb. weight.
Support.	One 1 lb. weight.
Spring balance (ounces and grams).	One 500 g. weight.
	Three 100 g. weights.

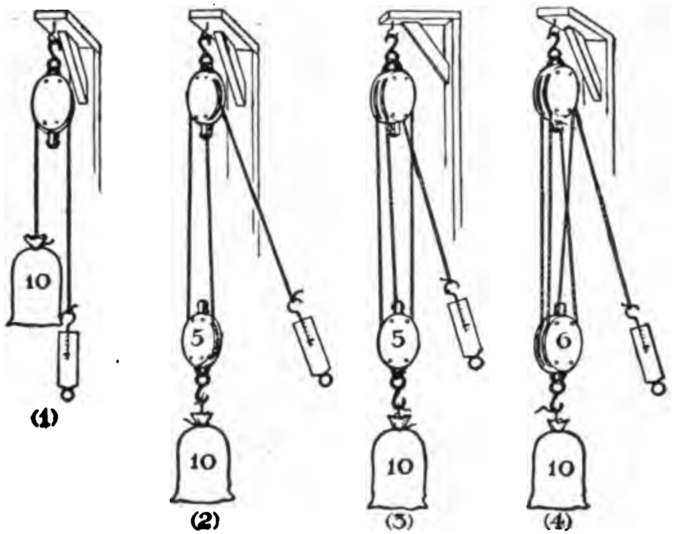

FIG. 8. Commercial pulleys with one, two, three, and four ropes supporting the weight.

The law of the pulley is: *If there is no friction, the force is equal to the weight divided by the number of ropes supporting the weight.* The force mentioned here is the force which would be required to support a given weight, if the pulleys were without friction and without weight.

Method 1. In all cases, use the law of the pulley, to calculate the force you expect to find, then find the force by experiment.

If the laboratory is equipped with the common commercial pulleys shown in Fig. 8, use these, and use weights ten times greater, in each case, than those mentioned below. If not, use small single pulleys, and when there are two pulleys in a block, as in (3) and (4) Fig. 8, use two single pulleys, one under the other for each double block, as shown in Fig. 9.

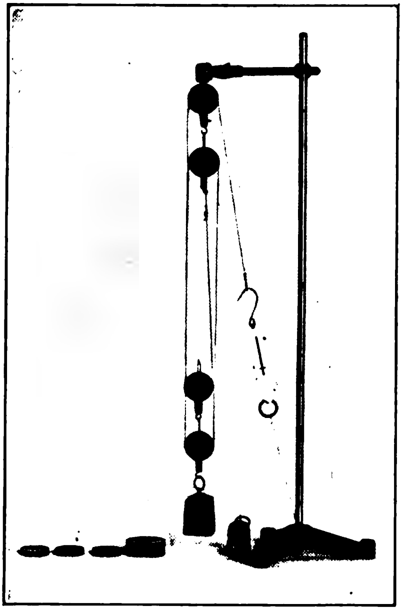

FIG. 9. Four small single pulleys so arranged that there are four strings supporting the weight.

(1) Arrange a single pulley as shown in (1) Fig. 8. Use a spring balance to find the force required to support a weight of 1 lb.

(2) Arrange two pulleys as shown in (2) Fig. 8. Find the force required to support the lower pulley alone; then find the extra force needed to support a weigh of 2 lb.

(3) Arrange three pulleys as shown in (3) Fig. 8. Find the force required to support the lower pulley alone; then find the extra force required to support a weight of 3 lb.

(4) Arrange four pulleys as in Fig. 9, or (4) Fig. 8. Find the force required to support the lower pulleys; then find the extra force required to support a weight of 2 lb.

(5) and (6) Make two experiments of your own.

NOTE.—The friction in the pulley bearings opposes any movement up or down; it therefore helps the spring balance to support the weight and makes the force recorded on the balance a little less than the real force. The real force is the average of the forces recorded when the weight is slowly raised and slowly lowered.

FORM OF REPORT

Exp.	Weight	Ropes Supporting Weight	Force	
			By calculation	By experiment
1	1 lb.	1		
2	2 lb.	2		
3	3 lb.	3		
4	2 lb.	4		
5				
6				

Method 2. Repeat the experiments given above, but use the following weights: (1) 500 g. (2) 500 g. (3) 600 g. (4) 800 g. In (2), (3), and (4) find the force in grams required to support the lower pulleys alone, and deduct these amounts from the total forces recorded on the spring balance. Make two experiments of your own.

FORM OF REPORT

Exp.	Weight	Ropes Supporting Weight	Force	
			By calculation	By experiment
1	500 g.	1		
2	500 g.	2		
3	600 g.	3		
4	800 g.	4		
5				
6				

Does the law of the pulley hold in each case; that is, is the force in each case equal to the weight divided by the number of ropes supporting the weight?

Exercise 2. Pulley and Screw Appliances.

Name any pulley appliances in the school and state the advantage of each.

Measure the handle and pitch of at least two of the following screw appliances and calculate their advantage: meat chopper, faucet, fruit press, sealer, clamp. Consult page 17, *Physics of the Household.*

Make a rough diagram of each and mark on it the length of the handle, the pitch, and the advantage.

Home Exercise.

Repeat this exercise with pulley and screw appliances in your home.

Make a written report on this work.

Experiment 4. Common weights and measures.

To study some common weights and measures.

Sheet of paper 15″ × 15″.	Quart, gallon.
Yard stick.	Balance and 8 lb. weights.
Cup, pint.	Pail of $\frac{1}{8}$ cubic foot volume.

Method 1. **The linear, square, and cubic foot.**

On a piece of paper draw a square 1 foot on each side.

Divide it into square inches to find 1 square foot contains..... square inches.

Hold the yard stick upright at one corner of the square. Place your thumb 1 foot above the square and picture to yourself the size of 1 cubic foot. Find by calculation.

1 cubic foot contains...........cubic inches

2. **Liquid measure.**

With water find:

the number of cups in 1 pint =
the number of pints in 1 quart =
the number of quarts in 1 gallon =

3. **Weight.**

Examine the pound balance. Turn it on its side to see the inside.

Place a 1 lb. weight on the left hand pan and balance it by means of the beam weight. Find:

Each division on the beam scale =...........ounces.
The range of the beam scale =...........ounces.

To show that 1 cubic foot of water weighs 62.3 lb. Use a cubical pail $\frac{1}{2}$ foot long, $\frac{1}{2}$ foot wide, and $\frac{1}{2}$ foot deep. It contains $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$ cubic foot; therefore, if 1 cubic foot of water weighs 62.3 lb., this pail should hold $\frac{1}{8}$ of this amount, or 7 lb. $12\frac{1}{2}$ oz.

Place the pail on one pan and balance it with weights. Add 7 lb. $12\frac{1}{2}$ oz. to the weight pan and fill the pail with water.

$\frac{1}{8}$ cubic foot of water weighs...................
therefore 1 cubic foot of water weighs...........

Experiment 5. Metric weights and measures.

To study metric weights and measures.

Sheet of paper 12″ × 12″.	Quart measure.
Meter stick.	Gram balance.
Liter measure.	Pound balance.

Method 1. **The linear, square, and cubic decimeter.**

Draw a line and mark off a length of 1 decimeter.

(NOTE. — When making measurements with a meter stick, yard stick, etc., place the stick on its edge so that the scale may be brought as near as possible to the object measured.)

Divide the 1 decimeter into centimeters to find:

1 decimeter = ... cm.

Draw a square, 1 decimeter on each side. Divide it into square centimeters to find:

1 square decimeter = ... sq. cm.

Hold the meter stick upright at one corner of this square, place your thumb 1 dm. above the square and picture to yourself the volume of 1 cubic decimeter. By calculation find:

1 cubic decimeter = ... c.c.

(1 cubic decimeter is also called a *liter*.)

Measure the inside diameter and depth of a liter measure and calculate its volume in c.c. to find

1 liter = ... c.c.

(NOTE. — The volume of a cylinder $= \pi \times (\text{radius})^2 \times$ depth, and $\pi = 3.1416$ or $\frac{22}{7}$ nearly.)

2. **Relation between volume and weight.**

Examine the gram balance. Remove the pans, and the beam. Replace them, place the rider at zero, and balance the pans by means of the nut at the right hand side of the beam.

Place a 10 g. weight on the left pan and balance it by means of the rider to determine:

The smallest division on the beam scale =............g.
The range of the beam scale =............g.

Place a liter measure on the left pan and balance it. Then add 1000 g. to the right pan and fill the liter measure with water to find:

1 liter of water weighs............g.
∴ 1 c.c. of water weighs............g.

3. **Relations between common and metric measures.**

Draw on paper a line 10 inches long and measure it in centimeters to find:

10 inches =............cm.
∴ 1 inch =............cm.

Use a liter and a quart measure to find:

1 quart =............liters (approx.)

Weigh a 1 lb. weight in grams to find:

1 lb. =............grams

Weigh a kilogram weight in pounds to find:

1 kilogram =............lb.

Exercise 3. Kitchen Measuring Appliances.

A well-equipped kitchen will have appliances for measuring volume, weight, oven temperature, and time.

Name the measuring appliances in your school kitchen.

Use salt to find:

the number of level teaspoonfuls in one level tablespoonful.

the number of level tablespoonfuls in one level measuring cup.

Consult page 305, *Physics of the Household.*

Home Exercise.

Repeat this exercise with the measuring appliances in your home and make a written report on your work.

Exercise 4. Water Supply.

Describe how your town or city is supplied with running water. Does the water come from a distant source at a higher level than the city; or is it pumped into a reservoir; or is it pumped directly into the city mains? Is the water purified, and if so, how?

NOTE. — It is recommended that the class be taken to the city pumping station, the filtering plant, and the reservoir.

Make a diagram of the city water-supply system showing the intake pipe, pumping station, filtering plant, and one water main. Consult page 30, *Physics of the Household.*

Home Exercise. Tell how your home is supplied with water.

If you have a private water supply system, make a diagram of it showing the path of the water from the source to one house faucet.

Make a written report on this work.

Exercise 5. Water Supply Plumbing.

Examine the water pipes in the school. Start at the point at which the water enters the building and follow the pipes to the water fixtures.

Make a rough diagram showing the course of the main cold water pipe and of at least two branches.

Where could you shut the water off in case a water pipe burst?

Home Exercise. Repeat this exercise with the water pipes in your own home and make a written report.

Exercise 6. Sewage Plumbing.

In the school trace, where you can, the path of the waste water from each fixture to the point at which it leaves the building.

Make a diagram showing the main soil pipe and the branches from at least two fixtures. Consult page 114, *Physics of the Household.*

What becomes of the sewage after it leaves the building?

Home Exercise. Repeat this exercise in your own home and make a written report.

Experiment 6. Law of Archimedes.

To verify the law of Archimedes for bodies that sink in water and for bodies that float on water.

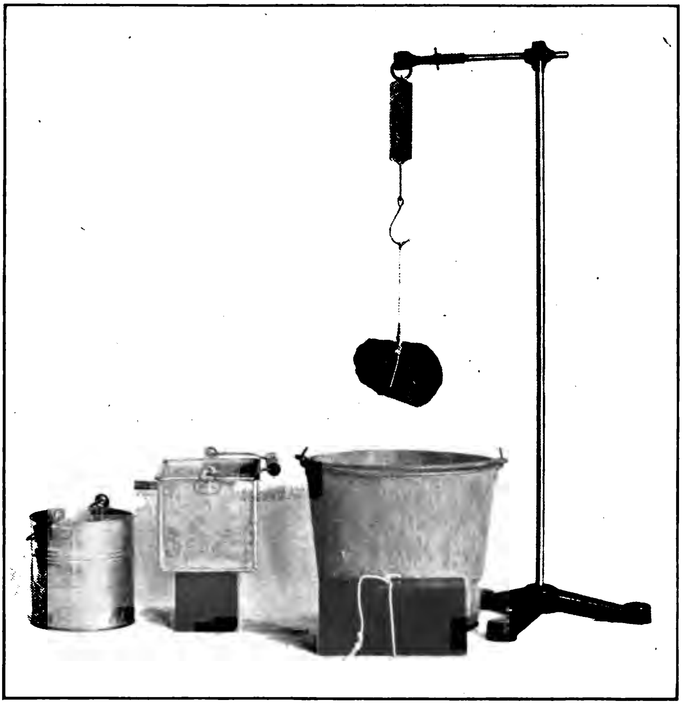

FIG. 10. Apparatus used to illustrate the law of Archimedes.

Twelve-quart pail.
Overflow pail.
Three-quart pail.
Spring balance.
Laboratory support.
Piece of rock weighing 2 or 3 lb.
Block of wood.

The law of Archimedes is: *A body when placed in a liquid loses weight equal to the weight of liquid displaced.*

Method. **Bodies that sink in water.**

To find the *loss in weight.* Weigh the piece of rock (Fig. 10) on a spring balance suspended from a stand. This is the weight of the rock in air. Now suspend the rock in a 12-quart pail of water and find its weight in water. The difference is the loss in weight in water.

weight of rock in air	=............
weight of rock in water	=............
loss in weight	=............

To find the *weight of water displaced* by the rock. Fill the overflow pail with water until water runs out at the spout. Weigh the empty catch pail. Then lower the piece of rock slowly into the overflow pail and catch the water which overflows. Weigh the catch pail with the displaced water.

weight of catch pail + water	=............
weight of catch pail empty	=............
weight of water displaced	=............

You have now found the *loss in weight* when the rock is weighed in air and then in water, also the *weight of water displaced* by the rock. Is the loss in weight equal to the weight of water displaced? That is, do you verify the law of Archimedes for this heavy body?

Bodies that float on water. Repeat the experiment above, but use a block of wood instead of the piece of rock.

weight of wood in air	=............
weight of wood on water	=............
loss in weight	=............
weight of catch pail + water	=............
weight of catch pail empty	=............
weight of water displaced	=............

Do you notice that the block of wood loses all of its weight when placed in water? Is this *loss in weight* equal to the *weight of the liquid it displaces*, that is, do you verify the law of Archimedes for this floating body?

Experiment 7. Volume and density.

To learn how to find the volume and density of a body.

FIG. 11. Apparatus used to find: the volume of a body in three ways, and the density of a substance.

A solid metal cylinder.
Vernier calipers.
Micrometer calipers.
Graduated cylinder 100 c.c.
Density balance.
Vessel containing water.
Overflow pail.
Catch pail.

VOLUME

We will find the volume of a solid in three ways: (1) by measurement, (2) by finding the volume of liquid it displaces when entirely immersed, (3) by finding its loss in weight in water.

Method 1. To find the volume of a cylinder by measurement.

Measure the length of the cylinder three times by means of the vernier calipers and find the average length.

Measure the diameter of the cylinder in three places by means of the micrometer calipers and find the average diameter.

NOTE. — If the laboratory is not supplied with these calipers, make the measurements with a meter stick.

Calculate the volume of the cylinder in c.c. Volume of cylinder $= \pi \times (\text{radius})^2 \times$ length.

Method 2. To find the volume of a body by finding the volume of liquid it displaces.

It is evident that if the volume of a solid is, say 100 c.c., it will displace 100 c.c. of a liquid if immersed in the liquid. If its volume is 150 c.c. it will displace 150 c.c. of the liquid, etc. In other words the solid will displace its own volume of the liquid.

Fill an overflow pail with water and when it has stopped dripping immerse the cylinder in the water. Catch the water which overflows and measure its volume in c.c., using measuring flask or graduated cylinder. The volume of the liquid displaced is equal to the volume of the cylinder immersed.

Method 3. To find the volume of a body by finding its loss in weight in water. In your experiment on the law of Archimedes you learned that the *loss in weight* of a body when immersed in water is equal to the *weight of the water it displaces.* That is, if a body loses 100 g. in weight when weighed in water, it will displace 100 g. of water and, since 1 g. of water has a volume of 1 c.c., it will displace 100 c.c. of water, that is, its volume is 100 c.c. In other words, *the loss in weight in grams of a body immersed in water is equal to its volume in c.c.*

Find the weight in g. of the cylinder in air, then find its weight when immersed in water. The difference is its loss in weight in grams and therefore its volume in c.c.

DENSITY

The *density* of a substance is defined as *the weight of unit volume* of that substance; that is, it is the weight of 1 cu. ft., 1 cu. in., 1 c.c., etc. *In all scientific work,* unless otherwise stated, *the density of a substance is the weight in g. of 1 c.c. of the substance.*

To find the density of aluminium.

The cylinder you used above is made of aluminium and you have found its volume in c.c. and its weight in air in g. Use the volume found in method 1, and the weight in air found in method 3, to find the density of aluminium as follows:

....c.c. of aluminium weigh.........g.
∴ 1 c.c. of aluminium weighs...........g.
the density of aluminium............g. per c.c.

FORM OF REPORT

VOLUME

		1	2	3	average
Method 1.	Length of cylinder in cm.	=........			
	Diameter of cylinder in cm.	=........			
	Volume of cylinder	=........c.c.			
Method 2.	Volume of water displaced in c.c.	=........			
	Volume of cylinder	=........c.c.			
Method 3.	Weight of cylinder in g. in air	=........			
	Weight of cylinder in g. in water	=........			
	Loss in weight in g.	=........			
	Volume in c.c.	=........			

DENSITY

Weight of cylinder of aluminium in air =............g.
Volume of cylinder =............c.c.

$$\text{Density} = \frac{\text{weight in g.}}{\text{volume in c.c.}} = \ldots\ldots\ldots\ldots \text{g. per c.c.}$$

Experiment 8. Density of solids.

To find the density of a number of solids.

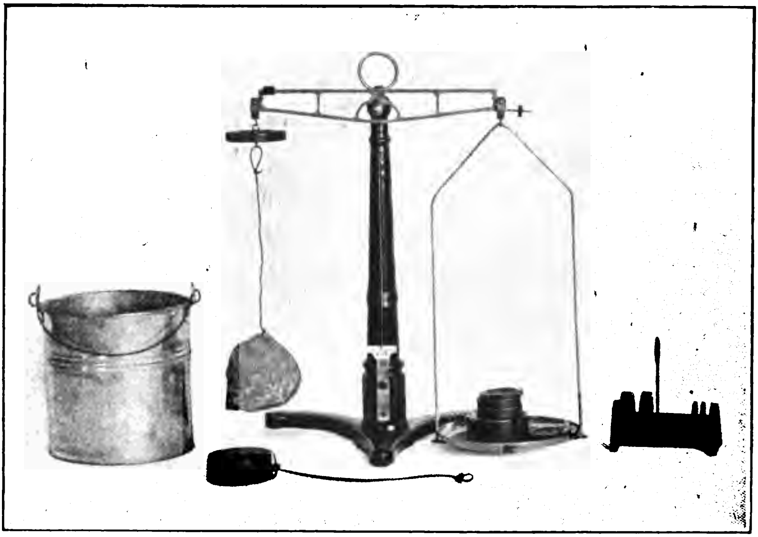

FIG. 12. Apparatus used to find the density of rock and iron.

Density balance.
Large vessel of water.
Pieces of rock, and of iron weighing 500 or 600 g.

As was stated in Experiment 7, the density of a substance is the weight in grams of one cubic centimeter of the substance. In Experiment 7 we found that the volume of a solid in c.c. is equal to its loss in weight in g. when weighed in air and then in water.

Method. Find the density of rock and of iron as follows:

Attach a cord to the solid and weigh it in air on the density balance, Fig. 12. Then immerse it in water and find its weight in water. The difference is its loss in weight in g. and its volume in c.c.

Calculate the density.

$$\text{Density} = \frac{\text{weight in air in g.}}{\text{volume in c.c.}}$$

FORM OF REPORT

	Rock	Iron
Weight in air in g.		
Weight in water in g.		
Loss in weight in g.		
Volume in c.c.		
Density in g. per c.c.		

Experiment 9. Density of liquids.

To find the density of a liquid.

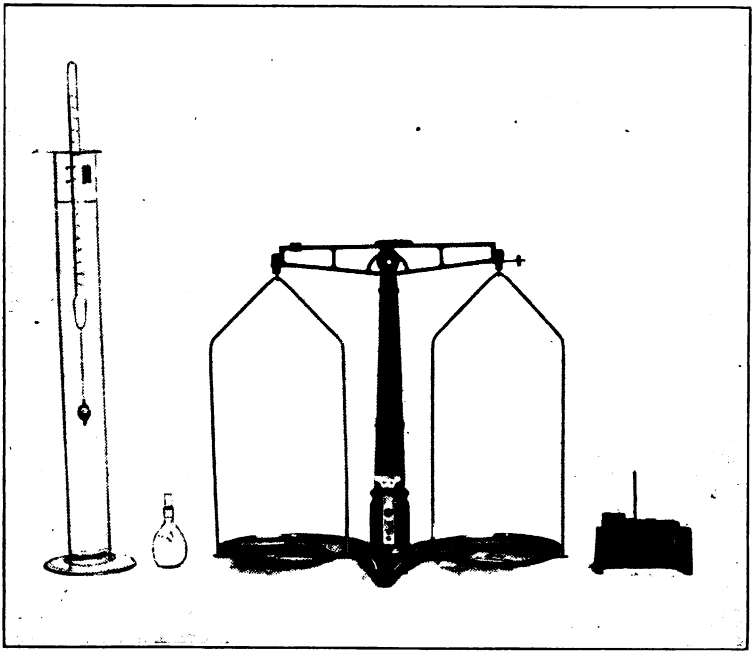

FIG. 13. Apparatus used to find the density of liquids.

Density bottle.
Gram scales.
Hydrometer.
Hydrometer jar.
Kerosene, gasoline, vinegar, or alcohol.

Method 1. Find the weight in g. of the density bottle, Fig. 13, when empty. Then find its weight when filled with water. The difference is the volume of the bottle in c.c., because 1 g. of water has a volume of 1 c.c. (If the volume of the bottle is known, it is not necessary to find its weight when filled with water.) Fill the bottle with the liquid, dry the outside, and find the weight of bottle + liquid. Subtract from this the weight of the empty bottle to find the weight of the liquid. Calculate the density of the liquid as follows:

$$\text{Density} = \frac{\text{weight of liquid in g.}}{\text{volume of liquid in c.c.}} = \ldots\ldots \text{g. per c.c.}$$

Method 2. Find the density by means of a hydrometer as follows:

Fill a cylinder, Fig. 13, with the liquid and place the hydrometer in it. Read the scale division opposite the surface of the liquid. This is the density of the liquid in g. per c.c.

FORM OF REPORT

Weight of bottle + water	=....g.	Weight of bottle + liquid	=....g.
Weight of empty bottle	=....g.	Weight of empty bottle	=....g.
Weight of water	=....g.	Weight of liquid	=....g.
Volume of bottle	=...c.c.	Density of liquid	= ....g. per c.c.

Density of liquid by means of hydrometer............g. per c.c.

(See table of densities page 138.)

Exercise 7. Gas Plumbing.

Trace the gas pipes from the point at which the gas enters the school to each gas fixture.

Make a diagram showing the course of the main gas pipe and of at least two branches.

Is your city supplied with natural gas or manufactured gas? If natural gas, tell where it comes from. If manufactured gas, tell how it is made.

Home Exercise.

Repeat this exercise in your own home and make a written report.

Read your gas meter once each month for six months; record the readings and dates, and compare your readings with those made by the gas company.

Experiment 10. Barometer and siphon.

To construct a barometer and to measure the pressure of the atmosphere with it. To illustrate the action of the siphon.

Two barometer tubes of different length and diameter.
Two evaporating dishes.
Mercury.
Small funnel.
Siphon.
Two pails of water.
Meter stick.
Support.

Barometer

Method. Fill a barometer tube with mercury, place the finger over the open end, invert the tube over a shallow dish of mercury and remove the finger under mercury. Measure, in cm. and also in inches, the height of the column of mercury in the tube above that in the dish.

Repeat the experiment with the second barometer tube.

You will notice that the columns of mercury are practically of the same height although you have used tubes of different areas of cross section, Fig. 14. (They would be of exactly the same height if all the air were removed from the space above the mercury.) We should find the heights to be the same if we made experiments with many tubes of different cross section. That is, the height of the column of mercury is independent of the area of cross section of the tube. This being the case we can consider the area of cross section of the tube to be anything we wish, for example, 1 sq. in. or 1 sq. cm.

To find the pressure of the atmosphere in lb. per sq. in. Assume that the tube has an area of cross section of 1 sq. in. Multiply this by the height of the column of mercury in inches to obtain the number of cubic inches of mercury in the column. Multiply the result by .49 lb., the weight of 1 cubic inch of mercury.

To find the pressure of the atmosphere in g. per sq. cm. Assume that the tube has an area of cross section of 1 sq. cm. Multiply

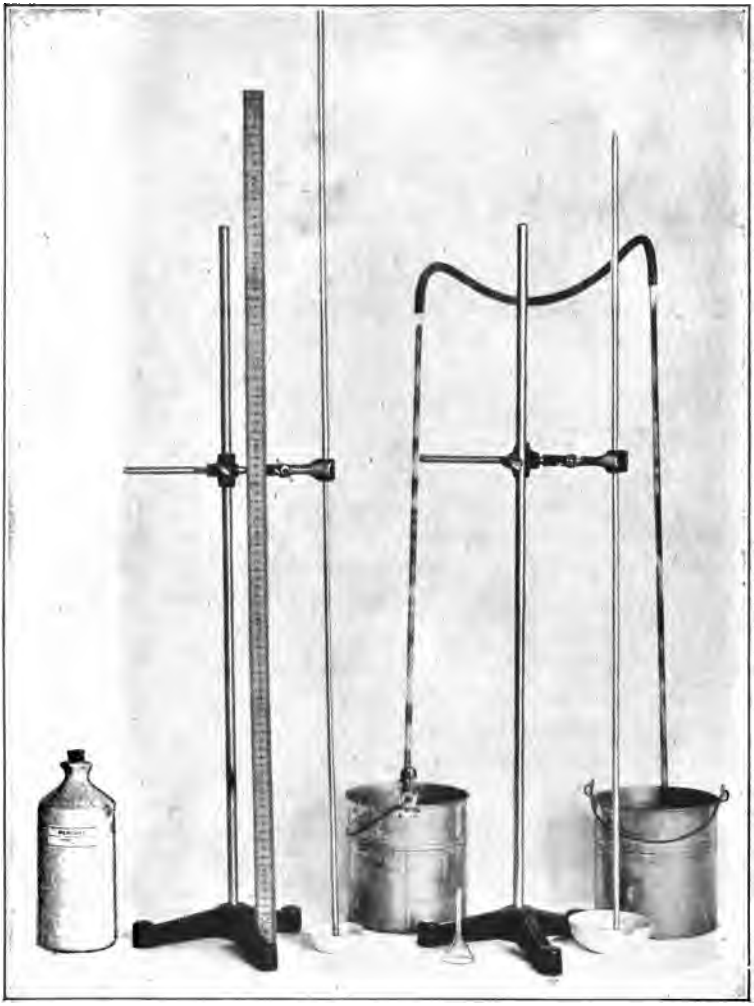

FIG. 14. Apparatus used to illustrate the action of the barometer and the siphon.

this by the height of the column of mercury in cm. and multiply the result by 13.6 g., the weight of 1 c.c. of mercury.

Siphon

Method. Make a U tube by connecting two glass tubes 3 or 4 feet long by means of a rubber tube, 1.5 feet long. Fill this U tube with water, place a finger over each end, invert the tube, place the ends in separate pails half full of water and remove the fingers under water.

Lower one pail and notice the direction in which the water flows. Raise this pail and lower the other. Is the direction of the flow reversed?

FORM OF REPORT

	1	2	Average
Height of mercury	in.	in.	
Height of mercury	cm.	cm.	

Pressure of atmosphere......lb. per sq. in.

Pressure of atmosphere......g. per sq. cm.

Exercise 8. Plumbing Traps.

Locate the trap under each type of water fixture in the school.

Open a trap under a sink or washbowl and clean it out.

Make a diagram showing the path of the water through the trap, and showing how the water seal is formed. Consult page 73, *Physics of the Household.*

Home Exercise.

Repeat this exercise in your own home and make a written report.

Experiment 11. Boyle's Law.

To illustrate Boyle's Law.

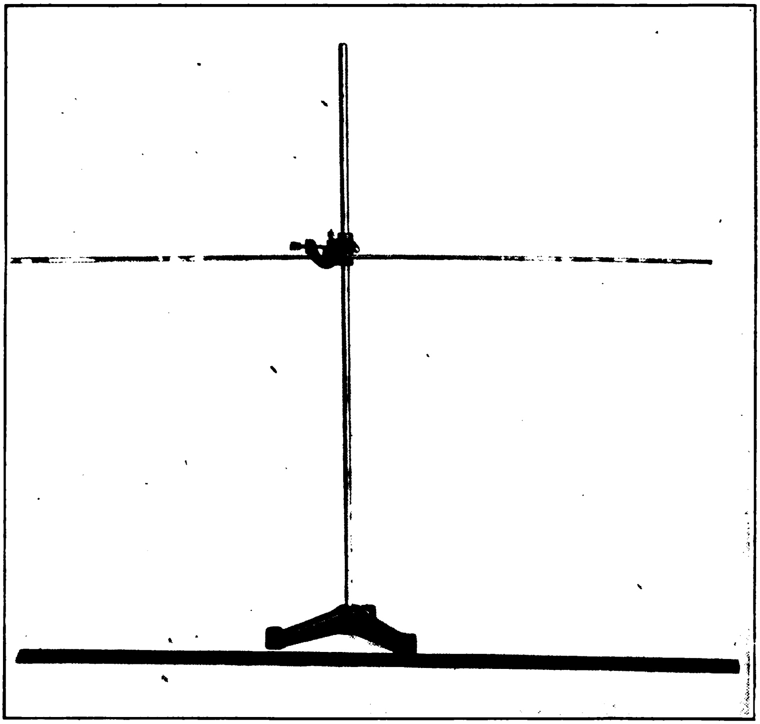

FIG. 15. Apparatus used to illustrate Boyle's Law.

Capillary tube 110 cm. long with a column of air between a column of mercury and the closed end.[1]

Support. Meter stick.

Boyle's Law is: *The volume of a gas varies inversely as the pressure on it.* That is, if the pressure on the gas is doubled, it is

[1] If this tube is not filled, fill it as follows. Draw a column of mercury about 50 cm. long into the tube; close one end with the finger and allow a column of air about 20 cm. long to enter the other end. Seal the latter end with sealing wax.

compressed to half its first volume; if the pressure is halved, the gas expands to twice its first volume, etc.

Method. You have on the table a tube which has a certain amount of air between a column of mercury and the closed end.

Lay the tube on the table and notice the length of the air column. Now stand it upright, with the closed end down, and notice that the air is compressed because the pressure on it is increased. Stand the tube upright, with the closed end up; notice that the air expands because the pressure on it is decreased.

(1) Lay the tube on the table and measure the length V_1 in cm. of the air column and also the length in cm. of the mercury column.

In this position the mercury is not exerting pressure on the gas and the total pressure P_1 on the gas is 1 atmosphere. If there is a barometer in the laboratory measure its height. If not, take the height of the barometer to be 76 cm. (1 atmosphere). Since the bore of the tube is uniform we may use the length of the air column as a measure of the volume of the air under different pressures.

(2) Stand the tube upright with the closed end down and measure the length V_2 of the air column. The pressure P_2 on the air in the tube is 76 cm. (1 atmosphere) + the length of the mercury column in cm.

(3) Stand the tube upright with the closed end up and measure the length V_3 of the air column. The pressure P_3 on the air in the tube is 76 cm. (1 atmosphere) – the length of the mercury column.

If the volume of the gas varies inversely as the pressure on it (Boyle's Law), then $\frac{P_2}{P_1}$ should equal $\frac{V_1}{V_2}$ and $\frac{P_3}{P_1}$ should equal $\frac{V_1}{V_3}$.

That is, the volume of the air should be decreased in the proportion the pressure is increased, and vice versa.

FORM OF REPORT

	Pressure	Volume
1	76 cm.	cm.
2	76 + cm.	cm.
3	76 − cm.	cm.

$\frac{P_2}{P_1} = \quad . \quad \frac{V_1}{V_2} = \quad .$

$\frac{P_3}{P_1} = \quad . \quad \frac{V_1}{V_3} = \quad .$

Do you verify Boyle's Law, that is, when the pressure on the gas is increased in (2) is the volume decreased in proportion; and when the pressure on the gas is decreased in (3) is the volume increased in proportion?

Exercise 9. Fire Extinguisher.

Examine the interior of one of the fire extinguishers in the school.

Close it, take it out-of-doors, turn it upside down and discharge it at a small bonfire, if convenient.

Charge the extinguisher according to the directions on the case, then discharge it again to make sure that you have done the work properly.

Charge it again and hang it where it will be convenient for immediate use.

Make a diagram showing the interior of the extinguisher. Consult page 70, *Physics of the Household.*

Home Exercise.

Repeat this exercise with the fire extinguisher in your home and make a written report.

Exercise 10. Vacuum Cleaner.

If there is a vacuum cleaner in the school, examine it to learn:

1. how a partial vacuum is produced;
2. the path along which the air travels;
3. how the air is freed from dirt.

Make a rough diagram showing the path of the air through the cleaner.

Home Exercise.

Repeat this exercise with the vacuum cleaner in your own home and make a written report.

HEAT

Experiment 12. Thermometers.

To find the fixed points of a Fahrenheit thermometer and of a centigrade thermometer.

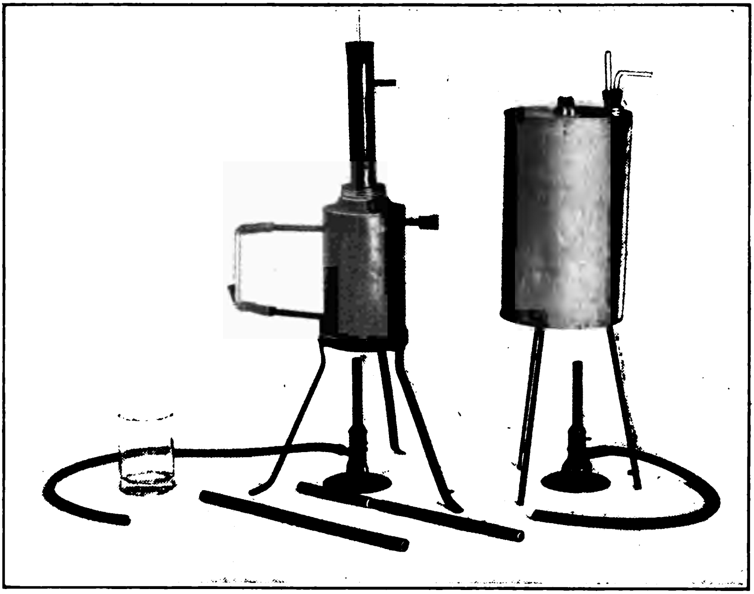

FIG. 16. Two types of apparatus used to find the fixed points of thermometers.

Glass full of snow or ice, and water.	Boiler.
Fahrenheit thermometer.	Tripod.
Centigrade thermometer.	Burner.

The *fixed points* of a thermometer are *the temperature of melting ice or snow* and *the temperature of the steam formed by water boiling under a pressure of one atmosphere.*

Method. To find the temperature of melting ice or snow. Fill a glass with snow or ice and add a little water. Place the thermometers in this and note the lowest temperature recorded on each. If the thermometers do not record 0° on the centigrade and 32° on the Fahrenheit, it is the thermometers which are in error and not the ice. Record the error of each.

To find the temperature of the steam formed by water boiling under a pressure of one atmosphere. Pour water into the boiler, on the right, Fig. 16, to a depth of 2 or 3 inches. Pass the top of the thermometer through one hole of a two-holed stopper until the 100° C. or 212° F. line is just exposed but with the bulb above the water in the boiler. Place a bent tube in the other hole to divert the steam and insert the stopper in the opening of the boiler. If you use a boiler similar to that on the left, Fig. 16, pass the thermometer through a one-hole stopper and allow the steam to escape from the outlet beneath. Boil the water and allow the steam to pass for one or two minutes. Read the temperature and if the barometer stands at 76 cm. (1 atmosphere exactly) note the error of the thermometer.

Repeat with the other thermometer.

FORM OF REPORT

	Fahrenheit	Centigrade
Temperature of melting ice	° F.	° C.
Error of thermometer	° F.	° C.
Temperature of steam	° F.	° C.
Error of thermometer	° F.	° C.

Exercise 11. Thermometers.

Examine the wall thermometer in the school and observe how high and how low it reads.

Make a diagram of the scale.

Examine the oven thermometer on the school range.

Make a diagram representing its working parts.

Home Exercise.

Repeat these exercises with the thermometers in your home and make a written report.

Experiment 13. Expansion of brass.

To find the coefficient of linear expansion of brass.

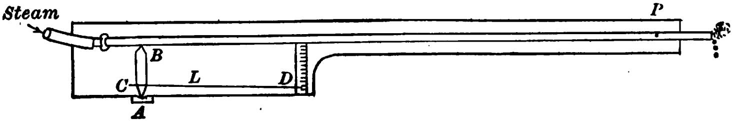

FIG. 17. Diagram of the apparatus used to measure the linear coefficient of expansion of brass.

Expansion apparatus.	Burner.
Boiler.	Thermometer.

The *coefficient of linear expansion* is *the expansion per unit length per degree change in temperature.* We will determine the expansion in cm. of a tube of brass 1 cm. long for a change in temperature of 1° C.

Method. Measure in cm. the length of the pointer *CD*, Fig. 17, from the end *D* to the middle of the arm *AB*. Measure the arm *AB* by means of the micrometer calipers (or meter stick if the calipers are not available). Divide the length of the pointer *CD* by the length of the arm *AB* to determine how many times a movement of *B* is magnified by *D*.

Clamp or secure the brass tube at the point *P* near one end and place the pointer in position near the other end. Find the length in cm. of the tube between *P* and *B*. Place the thermometer in the tube at end *P* and record the temperature of the tube.

When everything is ready read carefully and record the position of the end *D* of the pointer on the scale. Then place the burner under the boiler and allow the steam to pass freely for one or two minutes. Read carefully and record the new position of the pointer *D*, and the temperature of the steam. Calculate the coefficient of expansion of brass, that is, the expansion in cm. of a tube 1 cm. long for a change in temperature of 1° C.

Example. A brass tube is 90 cm. long from *P* to *B*. The pointer *CD* is 22.5 cm. long and the arm *AB* is 1.5 cm. long. The end of the pointer moves 2 cm. when the temperature changes from 20° to 100° C What is the coefficient of expansion of the brass?

Pointer magnifies 22.5 ÷ 1.5 = 15 times.

Actual expansion = 2 ÷ 15 = .133 cm.

A bar 90 cm. long warmed 80° C. expands .133 cm.

A bar 1 cm. long warmed 1° C. expands $\frac{.133 \text{ cm.}}{90 \times 80}$.

Coefficient of expansion $= \frac{.133}{90 \times 80} = .000018.$

FORM OF REPORT

Length of pointer	=	cm.	Length of brass tube	=	cm.
Length of arm	=	cm.	Temperature at beginning	=	° C.
Magnification of pointer	=		Temperature at end	=	° C.
Pointer reading beginning	=	cm.	Difference	=	° C.
Pointer reading end	=	cm.			
Difference		cm.			
Coefficient of expansion of brass	=				

Experiment 14. Expansion of air.

To find the volume coefficient of expansion of air.

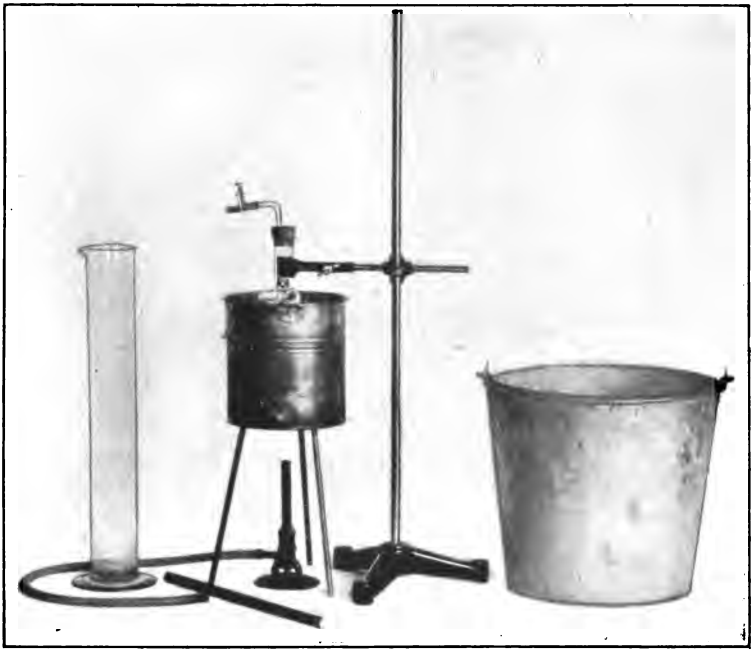

FIG. 18. Apparatus used to measure the coefficient of volume expansion of air.

Flask about 1000 c.c.	Pail, 12-qt.
Rubber stopper with one hole.	Stand.
Tube and clip.	Burner.
Measuring cylinder, 1000 c.c.	Ice
Pail, 3-qt.	

The volume coefficient of expansion of any gas is the expansion, per degree change in temperature, of unit volume measured at 0° C.

Method. We will heat a volume of air to 100° C. and then cool it to 0° C. and find how much it contracts in volume. This contraction is the same as the expansion would be if we did the reverse, that is, started at 0° C. and heated the air to 100° C.

Place the dry flask with stopper and clip in a 3-qt. pail of water as shown in Fig. 18. Boil the water vigorously for 2 or 3 minutes, then close the clip and invert the flask in a 12-qt. pail of ice water. Open the clip under water and allow the water to enter. Close the clip, remove the flask and measure the volume of water which entered. Now fill the flask with water to the bottom of the stopper and find its total volume.

Calculate the volume coefficient of expansion of the air as follows: The volume of the air at 100° C. is equal to the total volume of the flask. The volume of the air at 0° C. is equal to the total volume of the flask minus the volume of water which entered the flask. The volume of the water which entered is the volume this air at 0° C. would expand when warmed for 0° C. to 100° C.

Example. The total volume of the flask = 1189 c.c.
The volume of the water which entered = 319 c.c.
The volume of the air at 0° C. = 870 c.c.
870 c.c. of air at 0° C. warmed 100° C. expand 319 c.c.
1 c.c. of air at 0° C. warmed 1° C. expands $\frac{319}{870 \times 100} = .00366$.
Volume coefficient of expansion of air = .00366.

FORM OF REPORT

Total volume of the flask, or the volume of the air at 100° C. = ... c.c.
The volume of water which entered flask = ... c.c.
The volume of the air at 0° C. = ... c.c.
Change of temperature = 100° C.
Volume coefficient of expansion of air =

Exercise 12. Kitchen Range.

Examine the range in the school kitchen and trace the path of the air from the point at which it enters the range to the point at which it enters the stovepipe. Consult page 93, *Physics of the Household.*

Make a diagram showing the path of the air through the range when the oven is "on." Mark on it the position of each damper.

Describe the use of each damper.

Tell why the range "draws."

Home Exercise.

Repeat this exercise with the range in your home kitchen and make a written report.

Exercise 13. Heating System.

Examine the heating system of the school. Follow the pipes from the furnace to each radiator or register.

Is the school heated by means of hot air, hot water, or steam?

Make a diagram showing the path of the air, water, or steam, from the furnace to at least two radiators or registers. Consult pages 95, 96, 139, *Physics of the Household.*

Explain why the air, water, or steam moves as it does.

Home Exercise.

Repeat this exercise with the heating system in your own home and make a written report.

Exercise 14. Hot-Water Boiler.

Examine the system which supplies running hot water to the school kitchen.

Make a diagram illustrating this system.

Home Exercise.

Describe how your home kitchen is supplied with running hot water.

Make a diagram showing where the cold water enters, how it is heated, and where the hot water leaves. Consult page 97, *Physics of the Household.*

Make a written report.

Experiment 15. How to measure heat.

PART I: To illustrate the meaning of the heat units: British Thermal Unit, calorie, and kilogram calorie.

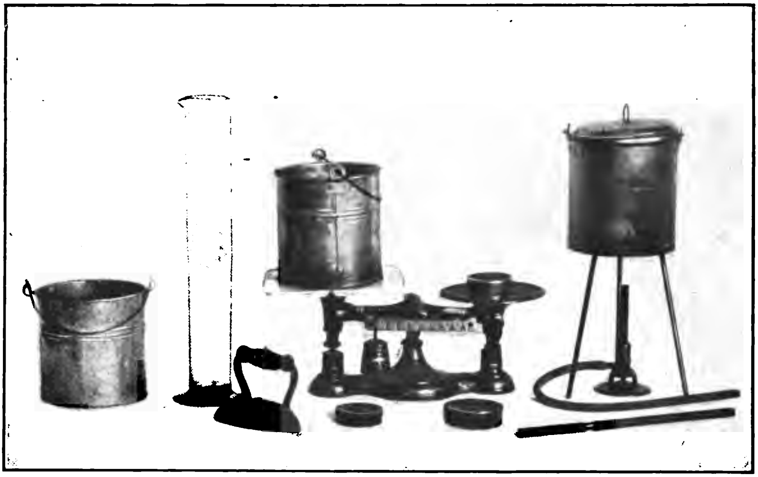

FIG. 19. Apparatus used to illustrate the heat units, and to show that different substances at the same temperature may contain different quantities of heat.

Pail, 3-qt.	Thermometers.
Balance, lb.	Burner and tripod.
	Measuring cylinder, 1000 c.c.

The *British Thermal Unit* (B.T.U.) is *the amount of heat required to raise the temperature of* 1 *lb. of water* 1° *F.*

The *calorie* is *the amount of heat required to raise the temperature of* 1 *g. of water* 1° *C.*

The *kilogram calorie*[1] *or Calorie* is *the amount of heat required to*

[1] When the term calorie is met in discussions of food values and the energy requirements of nutrition, it will almost invariably be found to refer to the kilogram calorie. The use of the capital C indicates that the greater calorie is intended. Many writers on food and nutrition use the simple term calorie for the kilogram calorie, assuming that readers will not be in doubt as to which calorie is meant inasmuch as the two units differ by a thousandfold.

raise the temperature of 1 *kg. of water* 1° *C.* The kilogram calorie = 1000 calories.

Method. **British Thermal Unit.** Weigh an empty three-quart pail and add to it a certain weight of cold water, say 4 lb. Find the temperature of the water in Fahrenheit degrees.

Place the pail over a burner for 2 minutes and again find its temperature. Calculate the number of B.T.U. received by the water.

Place the pail in a cool place for 2 minutes and find its temperature. Calculate the number of B.T.U. lost by the water.

Method. **Calorie and kilogram calorie.** Measure out 2000 c.c. (2000 g.) of cold water and pour it into the pail. Find the temperature of the water in centigrade degrees.

Place the vessel over a burner for 2 minutes and again find its temperature. Calculate the number of calories received by the water. Calculate the number of kilogram calories or Calories received by the water.

Place the vessel in a cool place for 2 minutes and find its temperature. Calculate the number of calories lost by the water. Calculate the number of kilogram calories or Calories lost by the water.

FORM OF REPORT

The .... lb. of water was warmed from ....° F. to ....° F. ∴ gain = ... B. T. U.

.... lb. of water was cooled from ....° F. to ....° F. ∴ loss = ... B. T. U.

The .... g. of water was warmed from ....° C. to ....° C. ∴ gain = ... calories.

The .... g. of water was cooled from ....° C. to ....° C. ∴ loss = ... calories.

The ....kg. of water was warmed from ....° C to ....° C. ∴ gain = ... Calories.

The ....kg. of water was cooled from ....° C. to ....° C. ∴ loss = ... Calories.

PART II. To show that different substances at the same temperature may contain different quantities of heat.

Three 3-qt. pails.	Burner.
Balance, lb.	Tripod.
Iron weight, 3 or 4 lb.	Fahrenheit thermometer.

Hot water (in a hot water bag) and hot iron (a hot flat-iron) are frequently used as footwarmers. Let us compare the amounts of heat given up on cooling by equal weights of hot water and hot iron at the same temperature. Proceed as follows:

Method. Place a pail on one pan of a scales and balance it; then place an iron weight on the other pan and add enough water to the pail to balance the iron. We now have equal weights of water and iron.

Place the iron in the pail, cover the pail and heat until the water boils vigorously. We now have equal weights of iron and water at 212° F.

While the water and iron are being heated, weigh two empty pails and add to each equal weights of cold water, say 2 lb. Take the temperature of the water in each pail.

Now place the hot iron in one pail and the hot water in the other and again find the temperature of the water in each pail.

Calculate the number of B.T.U. given up by the hot iron and by the hot water.

FORM OF REPORT

The hot iron warmed .... lb. of water from .... ° F. to .... ° F.
∴ the iron gave up.... B.T.U.
The hot water warmed .... lb. of water from ....° F. to .... ° F.
∴ the water gave up .... B.T.U.
.... at 212° F. contains more heat than .... at 212° F.

The reason for this is that water has a greater heat capacity than iron. You will understand this better when you have determined the heat capacity or specific heat of iron in Experiment 18.

Exercise 15. Cooking Utensils.

Handles. In the school kitchen name five cooking utensils with heat-resisting handles. Consult page 108, *Physics of the Household*.

Conductivity. Compare the heat conductivity of a copper or aluminum utensil with that of a tin utensil of the same size and shape as follows:

Heat equal weights of cold water in each vessel, one after the other on the same fire, for equal lengths of time, and find the change in temperature in each. Consult page 119, *Physics of the Household.*

Which is the better conductor?

Size of bottom. To show that food is warmed more quickly in a utensil with a large bottom than in one with a small bottom.

Heat equal weights of cold water in (1) a covered saucepan with a large bottom, (2) a covered tea or coffee pot with a small bottom, one after the other on the same fire, and find the time required to bring the water to the boiling point in each.

Covers. To show that food is heated more quickly in covered than in uncovered vessels.

Heat equal weights of cold water (1) in a covered vessel (2) in the same vessel uncovered, on the same fire, and find the time required to bring the water to the boiling point.

Home Exercise.

Repeat these exercises with cooking utensils in your own home and make a written report.

Exercise 16. Fireless Cooker.

Examine the school fireless cooker and make a diagram illustrating the interior. Consult page 108, *Physics of the Household.*

Test the cooker as follows: Place a weighed quantity of water (*e.g.* 10 lb.) in one of the kettles, cover and heat until the water boils (212° F.). Clamp down the cover and place the kettle in the cooker. Allow the cooker to stand closed for a certain time (*e.g.* 12 hours), find the temperature of the water, and calculate the number of B.T.U. of heat which have escaped through the sides of the cooker per hour.

To compare fireless cookers: Make the above test with two fireless cookers at the same time. The better cooker, other things being equal, is the one which loses the less heat per hour.

Home Exercise.

Make this test with the fireless cooker in your own home and make a written report.

Exercise 17. Thermos Bottle.

Examine the school thermos bottle and make a diagram illustrating its construction. Consult page 109, *Physics of the Household.*

Test it as follows: Pour into the bottle a definite weight (*e.g.* 1 lb.) of hot water and find its temperature. Allow it to stand closed for a known time (*e.g.* 12 hours), find the temperature of the water and calculate the number of B.T.U. of heat lost by the bottle per hour.

Repeat this with a definite weight of ice water and calculate the number of B.T.U. of heat which enter the bottle per hour.

Do you find that a thermos bottle keeps a thing cool better than it keeps it warm? Explain why. Consult page 110, *Physics of the Household.*

Home Exercise.

Make this test with your own thermos bottle and make a written report.

Exercise 18. Ventilation.

Examine the school ventilation system.

Follow the path of the air from the point at which it enters the school to the point at which it leaves.

Make a rough diagram representing the path of the air.

Home Exercise.

Make a diagram of the ventilating system in your home, if there is any.

Make a diagram showing how the soil pipe in your home is ventilated. Consult page 114, *Physics of the Household.*

Make a written report.

Experiment 16. Cooling effect of ice and of ice water.

To show that equal weights of ice and ice water have different cooling effects.

FIG. 20. Apparatus used to show that equal weights of ice and ice water have different cooling effects.

Two 3-qt. pails.	Balance, lb.
Two pails and strainer for ice water.	Fahrenheit thermometer.
Ice cr snow.	Burner and tripod.

Method. The temperature of melting ice is 32° F. or 0° C.; the temperature of ice water is the same. We wish to show that equal weights of these substances have very different cooling effects.

Make some ice water by stirring snow or ice in water, and when you are ready to use the ice water strain it through a cloth to remove all snow or ice.

Weigh an empty pail and add to it a certain weight of water, say 2 lb. Cover the pail and heat the water until it boils vigorously. Its temperature is then 212° F. Pour into this 1 lb. of ice water, and take the temperature after stirring for about 1 minute. Calculate the number of B.T.U. the ice water absorbed from the 2 lb. of water at 212° F.

Repeat this experiment, but use 1 lb. of dry ice instead of 1 lb. of ice water. Calculate the number of B.T.U. the ice absorbed from the 2 lb. of water at 212° F.

FORM OF REPORT

1 lb. of ice water cooled.... lb. of water from 212° F. to .... ° F.
∴ the 1 lb. of ice water absorbed.... B.T.U.
1 lb. of ice cooled .... lb. of water from 212° F. to ....° F.
∴ the 1 lb. of ice absorbed.... B.T.U.
.... has a greater cooling effect than the same weight of ....

The reason for this is that 144 B.T.U. of heat are required to change 1 lb. of ice at 32° F. to 1 lb. of water at 32° F. You will understand this better after you have determined the heat of fusion of ice in Experiment 19.

Experiment 17. Heating effect of steam and of boiling water.

To show that steam and boiling water have very different heating effects.

FIG. 21. Apparatus used to show that equal weights of steam and boiling water at the same temperature have different heating effects.

Two 3-qt. pails.
Balance, lb.
Boiler.
Fahrenheit thermometer.
Burner and tripod.

Method. Steam under atmospheric pressure has a temperature of 212° F.; boiling water under the same pressure has the same temperature. We wish to show that equal weights of steam and boiling water have different heating effects.

Weigh an empty pail and add to it a certain weight of cold water, say 4 lb. Take the temperature of the water. Balance the pail and water on a scales and pass live steam into the water until a certain weight of steam has condensed in the water, say $\frac{1}{4}$ lb. Take the temperature of the water and calculate the number of B.T.U. the steam gave to the water.

Repeat this experiment, but use $\frac{1}{4}$ lb. of boiling water instead of $\frac{1}{4}$ lb. of steam. Calculate the number of B.T.U. the boiling water gave to the cold water.

FORM OF REPORT

The .... lb. of steam warmed .... lb. of water from ....° F. to ....° F., ∴ the steam gave up .... B.T.U.

The .... lb. of boiling water warmed .... lb. of water from ....° F. to ....° F., ∴ the boiling water gave up .... B.T.U.

A given weight of ...... has a greater heating effect than the same weight of ......

The reason for this is that 1 lb. of steam at 212° F. gives up 966 B.T.U. of heat when it changes to 1 lb. of water at 212° F. You will understand this better when you have determined the latent heat of steam in Experiment 20.

Experiment 18. Specific heat.

To find the specific heat of iron, lead and aluminium.

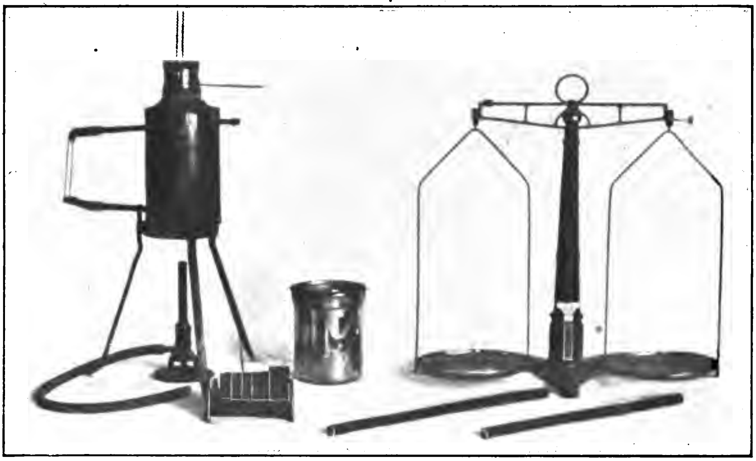

FIG. 22. Apparatus used to measure the specific heat of solids.

Boiler with dipper.
Calorimeter.
Two thermometers.
Balance.
Burner and tripod.
Lead shot, iron nails and aluminium pellets.

If we measure heat in B.T.U. the *specific heat* or *heat capacity* of any substance may be defined as *the number of B.T.U. required to raise the temperature of* 1 *lb. of the substance* 1° *F.*, or *the number of B.T.U. given up when* 1 *lb. of the substance cools* 1° *F.*

If we measure heat in calories the *specific heat* or *heat capacity* of any substance may be defined as *the number of calories required to raise the temperature of* 1 *g. of the substance* 1° *C.* or *the number of calories given up when* 1 *g. of the substance cools* 1° C.

The number found for the specific heat is the same, no matter which system of measurement we use.

In the previous experiments in heat we have measured heat in

B.T.U. In the three following experiments we will measure heat in calories, in order to obtain experience in the use of this heat unit.

It is suggested that three students, or three pairs of students, make this experiment side by side; the first student, or pair of students, using iron, the second, lead and the third, aluminium. Then let each student, or pair of students, copy the results obtained by the other two.

We propose to find the specific heat of the metals by the "method of mixtures." This method is as follows: A known weight of the metal at a known high temperature is dropped into a known weight of water at a known low temperature and the resulting temperature is determined.

Method 1. Weigh out 1000 g. of lead shot, or 250 g. of small iron nails, or 200 g. of aluminium pellets. Place them in the dipper of the boiler, Fig. 22; insert a thermometer bulb to about the middle and cover with a loose fitting cork. Heat until the temperature is about 95° C.

While the metal is heating, weigh the inner vessel of the calorimeter and add to it 200 g. of water at about 5° or 10° C. below the room temperature. When you find that the metal has reached about 95° C., read the temperature of the water to .1° C. and then add the metal to the water without splashing. Stir the contents for one minute and read the temperature to .1° C.

Calculate the specific heat of the metal in the manner illustrated in the following example:

One thousand g. of lead at 95° C. placed in 200 g. of water at 15° C. warms the water to 26° C. What is the specific heat of the lead?

If there has been neither loss nor gain of heat, in the whole apparatus, we know that the heat received by the water is that given up by the lead. We can calculate the amount of heat received by the water (since the heat required to warm 1 g. of water 1° C = 1 calorie), and this is the amount of heat given up by the lead.

The water was heated from 15° C. to 26° C., or through 11° C.; therefore the water received from the lead 200 × 11 = 2200 calories of heat.

The lead cooled from 95° C. to 26° C. or through 69° C. We can say then:

1000 g. of lead in cooling 69° C. gave up 2200 calories.

$\therefore$ 1 g. of lead in cooling 1° C. gave up $\frac{2200}{1000 \times 69} = .031$ calorie.

The specific heat of lead = .031 calorie.

NOTE: You have been asked to make this experiment in order that you might learn the common *method* of obtaining the specific heat of substances. You cannot expect your results to be accurate because you have not been asked to take into account the heat losses; for example, the heat lost in warming the calorimeter, the heat lost in transferring the metal from the boiler to the calorimeter, etc. You may be satisfied with your result if it is within 10 per cent of the correct value.

FORM OF REPORT

	IRON	LEAD	ALUMINIUM
Weight of metal, g.			
High Temperature of metal, °C.			
Low Temperature of metal, °C.			
Change of temperature of metal, °C.			
Weight of water, g.			
High Temperature of water, °C.			
Low Temperature of water, °C.			
Change of temperature of water, °C.			
Specific heat			

Method 2. If the laboratory is not equipped with the boiler shown in Fig. 22 and with a calorimeter, the specific heat of the metals can be determined with the apparatus mentioned below.

Two 3-qt. pails.
Balance.
Thermometer.
Burner and tripod.
Iron, lead, and aluminium.

Attach a piece of cord to a solid piece of metal and weigh it. Place the metal in a pail half full of water and heat it until the water has boiled for 2 or 3 minutes.

NOTE. — It is recommended that the student use large pieces of metal weighing about 2000 g. They give more accurate results than small pieces because: they can be weighed more accurately; and they produce greater changes in temperature, which can be measured more accurately.

With a measuring cylinder measure out 2000 c.c. (2000 g.) of water at a temperature about 5° C. below that of the room, and pour it into a 3-qt. pail.

When the metal is warmed (its temperature is 100° C.) take the temperature of the cold water to .1° C. Place the hot metal in the cold water, stir for one minute and take the temperature again to .1° C.

Calculate the specific heat of the metal as illustrated in the following example:

A piece of iron weighing 2000 g. is warmed to 100° C. and then placed in 1500 g. of water at 15° C. The resulting temperature is 25° C. What is the specific heat of iron?

The 1500 g. of water was warmed from 15° C. to 25° C. or through 10° C., therefore the water received $1500 \times 10 = 15000$ calories of heat from the hot iron.

The 2000 g. of iron cooled from 100° C. to 25° C. or through 75° C. We can say then:

2000 g. of iron in cooling 75° C. gave up 15000 calories of heat.

$\therefore$ 1 g. of iron in cooling 1° C. gave up $\frac{15000}{2000 \times 75} = .1$ calorie.

Specific heat of iron = .1.

For the reasons given above you may be satisfied with your results if they are within 10 per cent of the true value.

FORM OF REPORT

	IRON	LEAD	ALUMINIUM
Weight of metal, g.			
High Temperature of metal, °C. . . .			
Low Temperature of metal, °C. . . .			
Change of temperature of metal, °C. . .			
Weight of water, g.			
High Temperature of water, °C. . . .			
Low Temperature of water, °C.. . . .			
Change of temperature of water, °C. . .			
Specific heat			

(Look up table of specific heats, page 138)

Experiment 19. Latent heat of fusion of ice.

To find the number of calories required to change 1 g. of ice at 0° C. to 1 g. of water at 0° C., that is, to find the latent heat of fusion of ice.

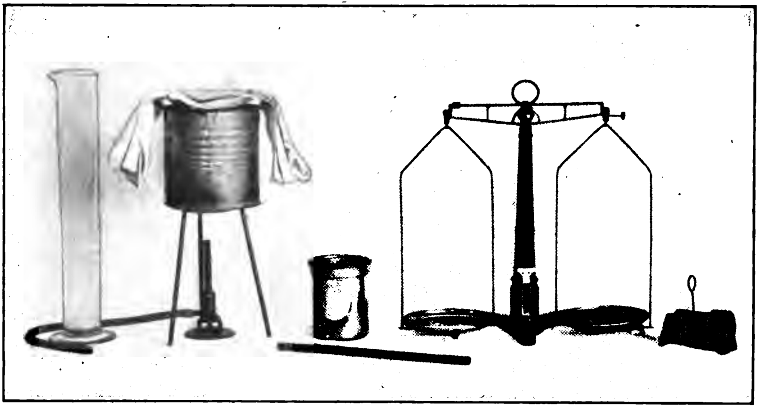

FIG. 23. Apparatus used to measure the latent heat of fusion of ice.

Calorimeter.	Balance.
Thermometer.	Ice.
	Towel.

Method 1. Weigh the inside vessel of the calorimeter and add to it 200 g. of water at about 10° C. above room temperature.

Break some clear ice into lumps about 1 in. in diameter and weigh out roughly about 50 g. of these lumps.

Take the temperature of the water to .1° C. Dry each lump with a towel and add it to the water. Stir until the ice is melted and read the temperature of the water to .1° C.

Weigh the inside vessel of the calorimeter again to find the weight of the ice used.

If there has been neither loss nor gain of heat, the heat given up by the water is that taken up by the ice, and since we can calculate the amount of heat given up by the water we know the amount taken up by the ice. It will be noticed that the ice takes up heat in two ways: first, when it changes from ice at 0° C. to water at 0° C., and second, when the resulting ice water is warmed from 0° C. to the final temperature.

Calculate the latent heat of fusion of the ice as illustrated in this example:

200 g. of water at 35° C. is cooled to 12° C. by 50 g. of ice. What is the latent heat of the ice?

The 200 g. of water is cooled from 35° C. to 12° C. or through 23° C.; therefore the water gave up 200 × 23 = 4600 calories.

The 50 g. of ice at 0° C. was changed to 50 g. of water at 0° C. and then the 50 g. of water was warmed from 0° to 12° C. This warming of the 50 g. of water from 0° C. to 12° C. required 50 × 12 = 600 calories.

The total heat received by the ice was 4600 calories, but 600 calories were required to warm the ice water. The difference, 4600 − 600 = 4000 calories, was used to melt 50 g. of ice; therefore 4000 ÷ 50 = 80 calories is the amount of heat required to melt 1 g. of ice.

The latent heat of fusion of ice = 80 calories.

NOTE. — You have been asked to make this experiment in order that you might learn the common *method* of finding the latent heat of fusion of ice. You cannot expect your results to be accurate because you have not been asked to take account of the heat gains; for example, the heat gained by the cooling of the calorimeter, and the heat gained because some water (melted ice) was added with the ice. You may be satisfied if your results are within 10 per cent of the correct value.

FORM OF REPORT

Weight of calorimeter	= ....g.	Temp. of water, beginning	= ....°C.
Weight of water	= ....g.	Temp. of water, end	= ....°C.
Weight of ice	= ....g.		

The latent heat of fusion of ice = ... calories per gram.

When we measure heat in calories as above, the latent heat of fusion of ice is 80 calories per gram, but when we measure heat in B.T.U. the latent heat of fusion of ice is $80 \times \frac{9}{5} = 144$ B.T.U. per pound. The reason for this is that the Fahrenheit degree is equal to $\frac{5}{9}$ of a centigrade degree and therefore there are $\frac{9}{5}$ as many in a given change of temperature.

Method 2. If the laboratory is not equipped with a calorimeter, the latent heat of fusion of ice can be determined with the apparatus given here.

Pail, 3-qt.	Thermometer.
Measuring cylinder 1000 c.c.	Ice.

Measure very carefully 2000 c.c. (2000 g.) of cold water, then pour it into a 3-qt. pail and warm it to about 35° C.

Break clear ice into lumps about the size of an egg and weigh out very roughly 500 g. of it.

Take the temperature of the water to .1° C.; dry the ice with a towel and place it in the water; stir until the ice is melted and take the temperature to .1° C.

Measure the water again and subtract 2000 c.c. to find the weight of ice added.

Calculate the latent heat of ice as shown in this example:

Two thousand g. of water at 32.5° C. is cooled to 10° C. by 500 g. of ice. What is the latent heat of ice?

The 2000 g. of water was cooled from 32.5 to 10°, therefore it gave up $2000 \times 22.5 = 45000$ calories of heat to the ice.

The 500 g. of ice at 0° C. was changed to 500 g. of water at 0° C. and then was warmed to 10° C. To warm 500 g. of water from 0° C. to 10° C. required $500 \times 10 = 5000$ calories of heat.

The ice absorbed in all 45000 calories of heat, but of this 5000 calories were required to warm the 500 g. of water from 0° to 10°; therefore the difference, $45000 - 5000 = 40000$ calories, was required to change 500 g. of ice at 0° C. to 500 g. of water at 0° C. We can say then:

To melt 500 g. of ice required 40000 calories.

∴ to melt 1 g. of ice required $\frac{40000}{500} = 80$ calories.

The latent heat of ice = 80 calories.

FORM OF REPORT

Weight of water	= .... g.	Temp. of water, end	= .... ° C.
Temp. of water, beginning	= .... ° C.	Weight of ice	= .... g.

Latent heat of ice =

As stated above, when we measure heat in calories, the latent heat of ice is 80 calories per gram, but when we measure heat in B.T.U. it is $80 \times \frac{9}{5} = 144$ B.T.U. per pound.

Exercise 19. Refrigerators.

Examine the school refrigerator and make a diagram illustrating the interior. Consult page 103, *Physics of the Household.*

Test it as follows: Empty the pan beneath the refrigerator, close the refrigerator for 10 or 12 hours, and find the weight of water in the pan. Calculate the number of B.T.U. of heat which entered the refrigerator per hour, using the fact that 144 B.T.U. of heat are required to change 1 lb. of ice at 32° F. to 1 lb. of water at 32° F. Consult page 135, *Physics of the Household.*

To Compare Refrigerators.

Make the above test with two refrigerators at the same time.

Home Exercise.

Repeat this test with the refrigerator in your own home and make a written report.

Exercise 20. Artificial Refrigeration.

As a class visit a refrigeration plant and learn all you can about it. Locate the compressor, condenser, evaporator, and the brine circulating system.

Make a rough diagram illustrating the system. Consult page 138, *Physics of the Household.*

Experiment 20. Latent heat of steam.

To find the number of calories of heat given up when 1 g. of steam at 100° C. changes to 1 g. of water at 100° C.; that is, to find the latent heat of steam.

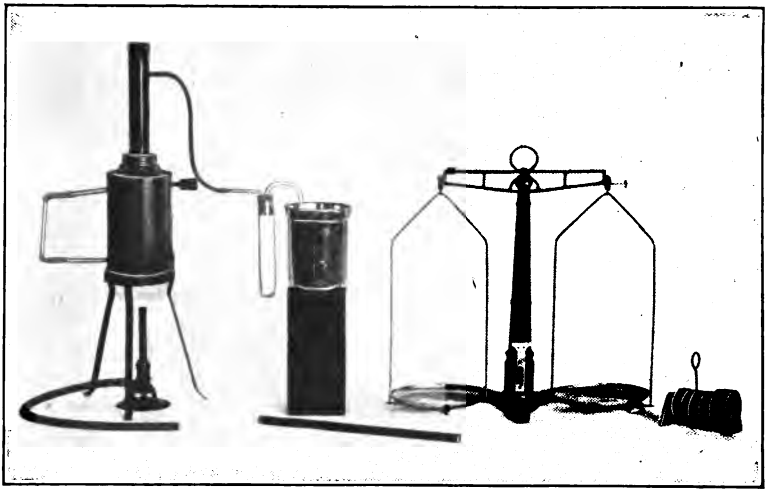

Fig. 24. Apparatus used to measure the latent heat of steam.

Boiler.	Tripod and burner.
Water trap.	Thermometer.
Calorimeter.	Balance and weights.

Method 1. Fill the boiler about half full of water and start it heating.

Weigh the inner vessel of the calorimeter. Make some ice water in a pail, strain it through a cloth to separate the ice, and weigh out about 200 g. of the ice water in the calorimeter.

When the steam is issuing freely from the boiler, attach the water trap; take the temperature of the water in the calorimeter to .1° C. (you will find the ice water has warmed to about 5° C.), and then place the delivery tube from the water trap about 2 cm. below the surface of the water.

Continue to pass steam into the water until the temperature is about 35° C.

Remove the delivery tube and take the temperature of the water to .1° C.

Weigh the calorimeter and water again to determine the weight of steam condensed in the water.

If there has been neither gain nor loss of heat, we know that the heat taken up by the water is that given up by the steam when it condenses from steam at 100° C. to water at 100° C. and then cools to the final temperature. We can calculate the amount of heat taken up by the water, and this is the amount given up by the steam.

Calculate the latent heat of steam as shown in this example:

200 g. of water at 5° C. is warmed to 35° C. by 10 g. of steam. What is the latent heat of steam?

The 200 g. of water is warmed from 5° C. to 35° C. or through 30° C., therefore the water receives from the steam $200 \times 30 = 6000$ calories of heat.

The 10 g. of steam at 100° C. changed to 10 g. of water at 100° C. and then cooled to 35° C. or through 65° C. When the 10 g. of water at 100° C. cooled through 65° C. it gave to the water $10 \times 65 = 650$ calories of heat.

The 10 g. of steam gave up 6000 calories in all, but 650 were given up in cooling; therefore $6000 - 650 = 5350$ calories were given up in changing from steam at 100° C. to water at 100° C.

We can say then:

10. g. of steam gave up 5350 calories in condensing.

$\therefore$ 1 g. of steam gave up $\frac{5350}{10} = 535$ calories.

The latent heat of steam is 535 calories per g.

(Correct value, 537 calories.)

NOTE.—You have made this experiment in order to learn the common *method* of determining the latent heat of steam. You cannot expect your results to be correct because you have not been asked to take into account the heat losses; for example, the heat lost in warming the calorimeter, the heat lost by the condensation of the steam before it enters the water, etc. You may be satisfied with your results if they are within 10 per cent of the true value.

FORM OF REPORT

Weight of calorimeter = ... g.	Temperature of water, end = ... ° C.
Weight of calorimeter + water = ... g.	Weight of calorimeter + water + steam = ... g.
Weight of water = ... g.	Weight of steam = ... g.
Temperature of water, beginning = ... ° C.	

Latent heat of steam = ... calories per gram.

When we measure heat in calories as above, the latent heat of steam is 537 calories per g., but when we measure heat in B.T.U. the latent heat of steam is $537 \times \frac{9}{5} = 966$ B.T.U. per pound. The reason for this is that one Fahrenheit degree is equal to $\frac{5}{9}$ of a centigrade degree and therefore there are $\frac{9}{5}$ as many in any given change of temperature.

Method 2. If the laboratory is not equipped with a boiler (Fig. 24) and a calorimeter, the latent heat of steam can be found with the apparatus listed below.

Sirup can boiler.	Balance and weights.
Burner and tripod.	Thermometer.
Water trap.	Two 3-qt. pails.

Start water heating in the boiler.

In a 3-qt. pail cool some water with snow or ice.

Attach the counterpoise weight to the left arm of the balance, attach the second 3-qt. pail to this and weigh the pail, then strain into the pail 1000 g. of ice water.

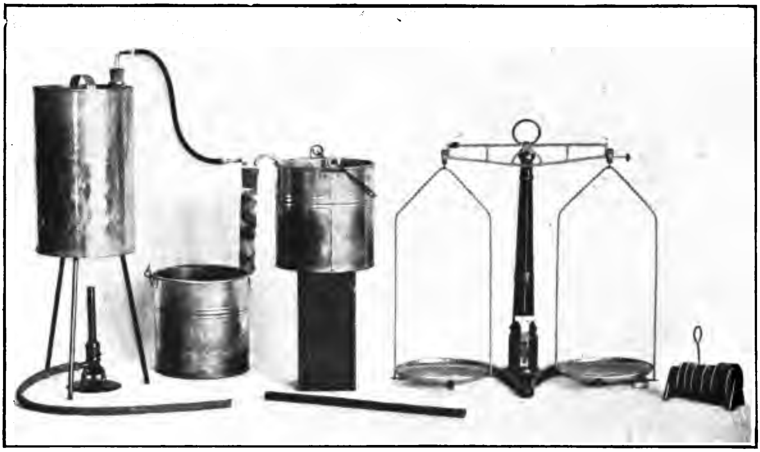

FIG. 25. Simpler apparatus used to measure the latent heat of steam.

Take the temperature of the water to .1° C. (it will be at about 5° C.) and pass steam into it until its temperature is about 35° C. Keep the delivery tube of the water trap about 2 cm. below the surface and stir the water continuously.

Take the temperature of the water to .1° C. and then weigh again to find the weight of steam.

Calculate the latent heat of steam as shown in the following example:

1000 g. of water at 5° C. is warmed to 35° by 50 g. of steam. What is the latent heat of steam?

The 1000 g. of water is warmed from 5° to 35° or through 30°, therefore the water received 1000 × 30 = 30000 calories of heat from the steam.

The 50 g. of steam at 100° C. changed to water at 100° C. and then cooled to 35° C. When the 50 g. of water cooled from 100° C. to 35° C. or through 65°, it gave up 65 × 50 = 3250 calories of heat.

The total heat from the steam was 30000 calories, but of this, 3250 calories came from the steam water; the difference, 30000 − 3250 = 26750 calories, was given up by 50 g. of steam at 100° C. when it condensed to water at 100° C.

We can say then:

50 g. steam in condensing gave 26750 calories.

$\therefore$ 1 g. steam in condensing gave $\frac{26750}{50} = 535$ calories.

The latent heat of steam is 535 calories.
(The true value is 537 calories.)

FORM OF REPORT

Weight of calorimeter = ... g.
Weight of calorimeter + water = ... g.
Weight of water = ... g.
Temperature of water, beginning = ... ° C.
Temperature of water, end = ... ° C.
Weight of calorimeter + water + steam = ... g.
Weight of steam = ... g.

Latent heat of steam = ... calories per gram.

As explained above, when we measure heat in calories the latent heat of steam is 537 calories per g., but when we measure heat in B.T.U. the latent heat of steam is $537 \times \frac{9}{5} = 966$ B.T.U. per lb.

Exercise 21. Fuels.

Find the average weight of fuel used in the school range per day and calculate the cost per day. Consult pages 152, 153, *Physics of the Household*.

Find the average amount of fuel used to heat the school per day and calculate the cost per day.

Home Exercise.

Repeat this exercise in your own home and make a written report.

NOTE.—If you use coal, find the average weight of a scuttle of coal and the number of scuttles used per day and calculate from these the cost of the range fuel per day. Also find the average weight of a shovelful of coal and the average number used in the furnace per day, then calculate from these the cost of the furnace fuel per day.

If you use petroleum as fuel, calculate the cost per day from the price per gallon and the average number of days a gallon lasts.

If you use gas as fuel, calculate the cost per day from the number of cubic feet used per day and the price per cubic foot.

If you use wood as fuel, consider 1 cord of hard wood to weigh 4000 lb. and 1 cord of pine 2000 lb., and calculate the cost from the weight of wood used per day.

ELECTRICITY AND MAGNETISM

Experiment 21. The simple cell.

To show that an electric current is produced when two different metals are placed in a solution of a salt, or of an acid, or of a base.

Two tumblers.
Strip holder.
Salt.
Acid solution.
Sticks of KOH or NaOH.
Galvanometer.
Strips of copper, zinc, lead, aluminium, iron, etc.
Rod of carbon.

Method. **Water.** Use strips of metal about 4 in. long and 1 in. wide.

Fill the tumbler ¾ full of water.

Use copper and zinc, connect with the galvanometer and place the strips in water.

Repeat with the carbon rod and zinc strip.

Do you notice a deflection of the galvanometer needle? (If the galvanometer is sufficiently sensitive you will notice a small deflection. A galvanometer is used to detect and measure an electric current.)

Salt solution. Lift the strips out of the water and stir a small handful of table salt in the water.

Try the metals in pairs.

Do two different metals in the salt solution produce a current? Do you notice that the current is sometimes in one direction and sometimes in the other?

Use the carbon rod and the zinc strip, and remember the direction in which the needle of the galvanometer turns. In any electric cell there are two different metals, and one metal is less readily dissolved than the other. The metal less readily dissolved is charged with positive electricity and is called the positive pole; the other is charged with negative electricity and is called the

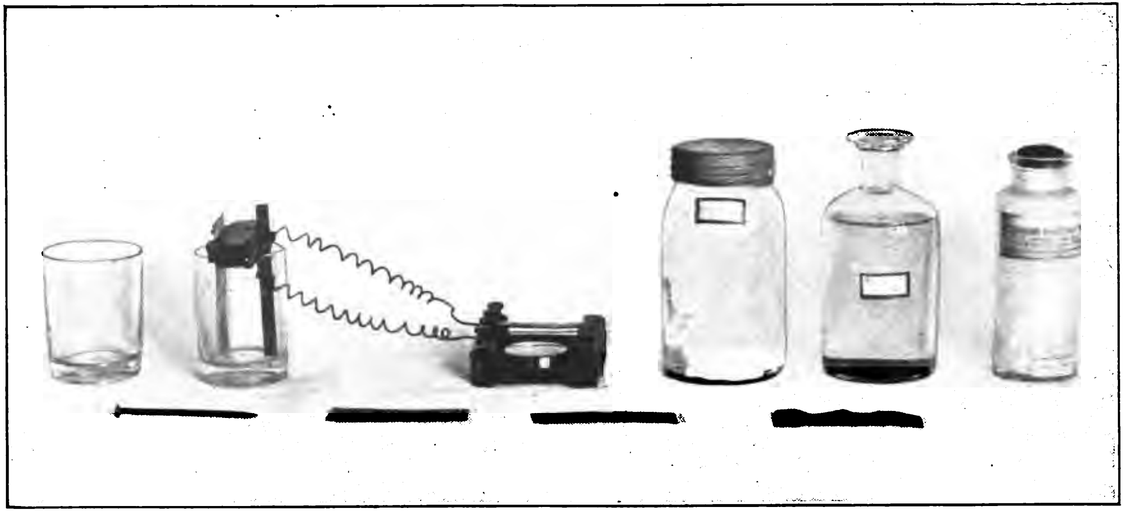

FIG. 26. Apparatus used to illustrate the simple cell.

negative pole. The electric current flows through the wire from the positive pole to the negative pole.

In the case of the carbon and zinc above, the current flows through the wire from the carbon to the zinc. If any other pair of metals turns the needle in the same direction as the carbon and zinc, you will know that the metal taking the place of the carbon is the positive pole and that taking the place of the zinc is the negative pole.

Acid solution. You will find on the table a large bottle of dilute sulphuric acid (1 part acid poured into 60 parts water). Empty out the salt solution, rinse and fill the tumbler $\frac{3}{4}$ full of the acid solution.

Try the metals in pairs. (Be careful not to get acid on your clothes. It would be well to have an empty tumbler at hand to hold the strips after you have used them.)

Do two different metals in the acid solution produce a current?

Solution of a base. Pour the acid solution back into the large bottle, rinse the tumblers and strips.

Fill the tumbler $\frac{3}{4}$ full of water and dissolve in it a stick of KOH or NaOH about 1 inch long.

Do two different metals in a solution of a base produce an electric current?

Empty out the solution and rinse the tumblers and strips.

You have shown that when two different metals are placed in a solution of a salt, acid, or base, a current is produced in the wire joining the metals. It has been found by experiment that when *any* two different metals are placed in a solution of *any* salt, acid, or base, a current is produced in the wire joining the metals.

Experiment 22. Magnets.

To study the properties of permanent magnets.

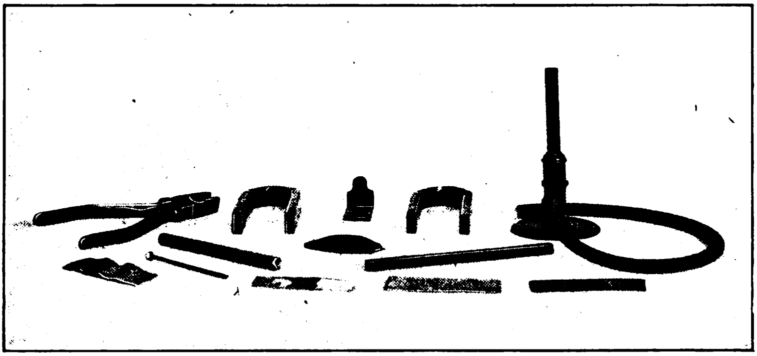

FIG. 27. Apparatus used to illustrate the properties of permanent magnets.

Two U magnets.
Bar magnet.
Two sewing needles.
Iron filings.
Bunsen burner.
Pliers.
Bar of soft iron.
Thread.
Pieces of iron, brass, lead, aluminium, wood, etc.

Method. **How does a magnet point?** Suspend a magnet, by means of a string attached at the middle or by means of a stirrup, in such a way that it is free to turn. Choose a place where there is no iron within 3 or 4 feet. After the string has untwisted for an hour observe the direction of the magnet poles. Do the poles point north and south?

What substances does a magnet attract? Apply a strong magnet to pieces of iron, steel, brass, lead, aluminium, wood, etc. What substances does a magnet attract?

Which poles attract each other and which repel? Apply the N pole of one magnet to the N and S poles of another. Repeat with the S pole. Which poles of two magnets attract each other? Which repel?

To make a permanent magnet. Use an ordinary sewing needle about $1\frac{1}{2}$ in. long, stroke it 2 or 3 times from the *eye* to the *point* with the N pole of a magnet. Does the needle pick up iron filings, that is, is it a magnet? Find the poles of the needle as follows: Place the needle on the table and move the N pole of the magnet along the table towards it in a line at right angles to the needle at the middle. Which end of the needle is a N pole? The point is the end last touched by the N pole; is it a N pole or a S pole?

Stroke the same needle 3 or 4 times from *eye* to *point* with the S pole of a magnet. Repeat the test with N and S pole of the magnet. Is the end last touched by the S pole a N or a S pole? Have you reversed the poles of the needle?

Magnetic induction. Place the needle, used above, on the table and remember which end is the N pole and which the S (test with a magnet if necessary). Place a piece of soft iron in front of the N pole of a magnet and about $\frac{1}{4}$ in. from it. Move the soft iron and magnet toward the needle in a line at right angles to the needle as above.

Does the soft iron become a magnet? Which pole, N or S, does the end of the soft iron farthest from the N pole of the magnet become? Which pole does the nearer end become?

Place the soft iron $\frac{1}{4}$ in. in front of the S pole of the magnet and repeat the experiment. Which pole, N or S, does the end of the soft iron farthest from the S pole of the magnet become? Which pole does the nearer end become?

The effect of breaking a magnet. Use the needle you stroked with the poles of the magnet. Cover it with iron filings and lift it out. Are the filings most numerous at the ends?

Test with a magnet to make sure which end of the needle is the N pole and which the S pole, then break the needle into two pieces. Cover each piece with filings. Are new poles formed?

Place the pieces on the table and test with a magnet to determine which of the new poles is N and which S.

Have two new magnets been made by breaking the needle?

Break one of the pieces again. Are two more new magnets made?

The effect of heating a magnet. Magnetize the second needle strongly by stroking it 3 or 4 times with the N pole of the magnet. Dip the needle in iron filings. Is it strongly magnetized?

Hold the needle with a pair of pliers and heat the ends red hot in turn. Place the needle in filings. Is it a magnet?

Remagnetize the needle and repeat.

Read up in the text book on the theory that each molecule of iron or steel is a magnet. Do these experiments support this theory?

Experiment 23. Magnetic fields.

To trace the magnetic lines of force in magnetic fields.

FIG. 28. Apparatus used to trace the magnetic lines of force in magnetic fields.

Bar magnet.
Two horseshoe magnets.
Glass plate.
Soft iron bar.
Iron filings in sifter.
Small compass.

Method. Place a bar magnet on the table and place over it a sheet of glass. Sift iron filings (from a cheesecloth bag or from a sifter) evenly over the glass. Tap the glass until the filings are in curved lines. The filings trace out magnetic lines of force in the plane of the glass.

Place a small compass at different positions on the glass where the lines are distinct. Does the needle take a position parallel to the lines of force in each position?

A magnetic line of force is assumed to run from N to S outside the magnet and from S to N inside the magnet. Does the N pole of the compass point in the direction the lines of force run?

Horseshoe magnet. Repeat this experiment, but use a horseshoe magnet instead of a bar magnet.

Does the N pole of the compass point in the direction the lines of force run?

Magnetic induction. Place a bar of soft iron (½ in. in diameter or larger and about 2 in. longer than the poles of the magnet are apart) across the poles of the horseshoe magnet but about 2 in. from the poles. Sift filings over the glass and find the magnetic lines of force as above. Do you notice that many magnetic lines of force run from the N pole to one part of the soft iron bar and then from the other part of the bar back to the S pole? Also that there are no magnetic lines of force beyond the soft iron bar? This shows that the lines pass through iron more readily than they do through air.

Two magnets. Place two horseshoe magnets 2 in. apart on the table with the S pole of the first opposite the N pole of the second and N pole of first opposite S pole of second. Trace the magnetic line of force with filings as above. Do you notice that the lines of force run from each N pole to both S poles?

Place the two horseshoe magnets 2 in. apart on the table with N pole of first opposite N pole of second and S pole of first opposite S pole of second. Trace the lines of force with iron filings as above.

Do you notice that the magnetic lines of force starting at the N pole of each magnet return to the S pole of the same magnet and that the magnetic lines of force of one magnet appear to repel those of the other?

Experiment 24. Magnetic effect of an electric current.

To study the magnetic effect of an electric current, the electromagnet, and the solenoid.

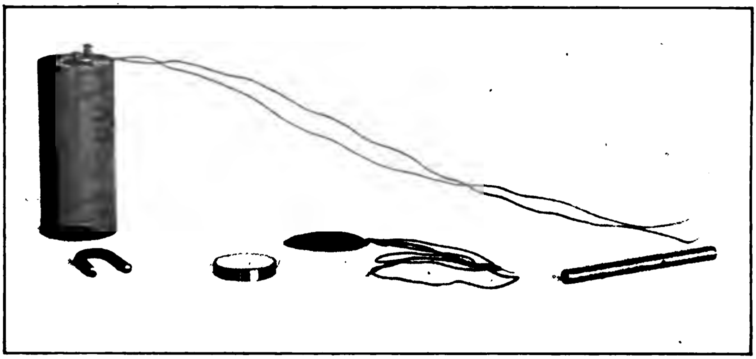

FIG. 29. Apparatus used to illustrate: the magnetic effect of an electric current, the electromagnet, and the solenoid.

Dry cell.	Soft iron bar.
Compass.	Soft iron horseshoe.
Iron filings.	Two pieces of insulated wire 2 feet long and one piece 8 feet long.

Method. Attach wires 2 feet long to the poles of a dry cell. Place a compass on the table and lay one wire over the compass *parallel to the needle.* Bring the bare ends of the wires together for an instant.

NOTE. — When using a dry cell do not allow the current to run longer than 10 or 20 seconds at one time.

Has the electric current a magnetic effect, that is, does it make the compass needle move?

Test the following rule, which enables us to determine the relation between the direction of the current and the direction of the magnetic lines of force produced by the current.

RULE: *Grasp the wire in the right hand with the extended thumb pointing in the direction the current flows; the fingers then point in the direction of the magnetic lines of force about the wire.*

To test this rule you must remember:

(1) That the electric current is assumed to flow in the direction the + electricity moves; in this case from the carbon pole of the dry cell, through the wire, to the zinc pole.

(2) That a magnetic needle places itself parallel to the lines of force of a magnetic field with its N pole in the direction the lines run.

Test the rule as follows:

Place the wire from the carbon pole over the compass, parallel to the needle:

(1) With the current flowing from N to S.

(2) With the current flowing from S to N.

Place the wire from the carbon pole under the compass, parallel to the needle.

(1) With the current flowing from N to S.

(2) With the current flowing from S to N.

Does the rule give you the direction of the magnetic lines of force in each case, that is, the direction the N pole turns?

Fold one wire and pass the current over the needle in both directions at once; be sure that the folded wire is exactly parallel to the needle. Is the effect zero? That is, does the magnetic field about one fold of the wire exactly counteract the magnetic field about the other?

Pass the current over and under the needle. Is the effect greater than when the current passes only in one direction? Apply the rule to each part of the current to determine whether the magnetic fields of each part of the current tend to turn the needle in the same direction.

Loop the wire 3 or 4 times about the compass parallel to the needle. Is the effect of the current still greater?

To determine the direction of an unknown current. Hide the dry cell behind a book and bring the wires out from under the book. Notice the direction the current moves the needle and use the rule to determine the direction the current is flowing in the wire. Practice this a number of times and check your results by following the wire back to the cell.

Electromagnet

To make an electromagnet, wind a bar of soft iron with 50 turns of insulated wire (you will need about 8 feet of wire for a bar ½ in. in diameter).

Hold one end of the bar near iron filings and pass a current through the wire. Is the bar a magnet?

Stop the current. Is the bar a magnet?

A bar of soft iron wound with insulated wire in this way is an *electromagnet,* and the important property of an electromagnet is that it is a magnet only when the current is flowing through the wire.

The following rule enables us to find the N pole of an electromagnet when we know the direction in which the current is flowing.

Rule: *Grasp the electromagnet in the right hand with the fingers pointing in the direction the current is flowing in the wire; the extended thumb then points to the north pole of the electromagnet.*

Test this rule as follows: Place the electromagnet on the table at right angles to a compass needle and about 2 in. from it. Pass the current through the wire first in one direction and then in the other. Does the rule give the N pole of the electromagnet in each case?

Wind a soft iron horseshoe with the wire to make a horseshoe electromagnet. Place the ends near iron filings and pass the current through the wire. Is the horseshoe a magnet?

Stop the current. Is the horseshoe a magnet? Test the rule for finding the N pole.

Solenoid

Make a solenoid by winding a dozen turns of wire on a lead pencil. Remove the coil from the pencil and place it on the table near a compass and at right angles to the needle. Pass the current through the coil. Is the coil a magnet?

A coil of wire with a current passing through it is called a *solenoid;* it is a magnet, but weaker than an electromagnet of the same size.

Test the rule for finding the N pole of an electromagnet on the solenoid. Does it enable you to find the N pole of the solenoid when you know the direction the current is flowing through the wire?

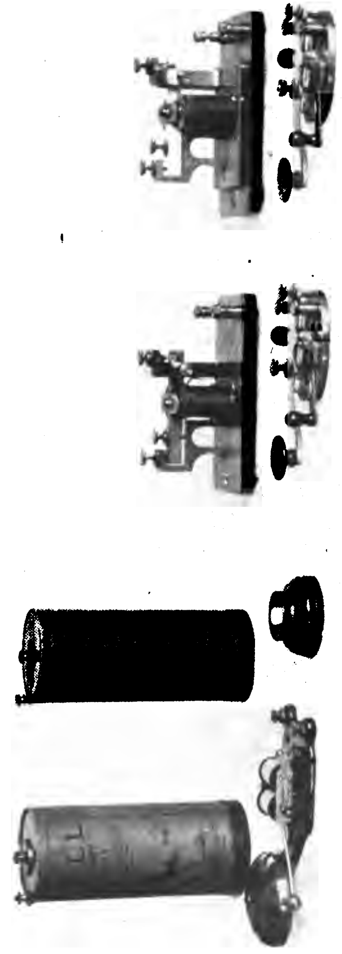

FIG. 30. Apparatus used to illustrate the working of an electric bell and of a telegraph line with two stations.

Experiment 25. Applications of the electromagnet.

To study the electric bell and the telegraph.

Electric bell.	Six insulated wires $1\frac{1}{2}$ feet long.
Push button.	Two insulated wires 8 feet long.
Two dry cells.	Two telegraph sounders.

Two keys.

As we continue our study of electricity we shall find that when it is necessary to move anything in or with an electrical appliance, an *electromagnet* is almost always used to produce the movement.

The Electric Bell

Method. Join an electric bell to a dry cell and push button in such a way that the bell rings when the button is pressed. Do you find the electromagnet?

Trace the path of the current through the bell.

Study the bell to find out why it continues to ring as long as the button is pressed. Consult the text book if necessary.

Make a diagram of the bell in your note book showing the path of the current through the bell.

The Telegraph

Join a sounder to a dry cell and key in such a way that the sounder sounds when the key is pressed. Do you find the electromagnet?

Follow the current through the sounder and key.

Note.—When using a dry cell do not allow the current to run for long at a time.

Let two groups of students join two such stations by two line wires in such a way that each station has a sounder, key, and cell, and that both sounders sound when either key is pressed, the other key being closed.

Make a diagram in your note book of two telegraph stations connected by two line wires, each station being equipped with sounder, key, and cell. See text if necessary.

Exercise 22. Bell Circuit.

Examine the electric doorbell of the school. Locate the push button, battery and bell, and draw on paper the path which the wires should take to connect these properly. Consult page 178, *Physics of the Household.*

Now follow the wires to determine whether they are as you have drawn them.

Unscrew the top of the push button and make a diagram of the interior. Consult page 179, *Physics of the Household.*

Remove the box of the bell and make a diagram of the wiring. Consult page 178, *Physics of the Household.*

What type of cell is used in the battery? Consult pages 164–167, *Physics of the Household.*

Home Exercise.

Repeat these exercises with the electric bell in your home and make a written report.

Experiment 26. Electric motor.

To study the electric motor.

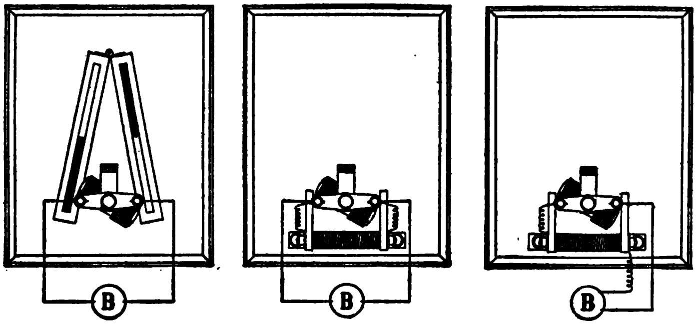

Fig. 1 Fig. 2 Fig. 3

FIG. 31. Diagrams showing the demonstration motor arranged: in Fig. 1, as a motor with permanent magnets in the field magnet; in Fig. 2, as a shunt wound motor with an electromagnet for the field magnet; in Fig. 3, as a series wound motor with an electromagnet for the field magnet.

Demonstration motor. Dry cell.
Compass.

Method. **The armature.** The moving part of the motor is called the *armature;* the split ring on one end of the armature is called the *commutator;* and the magnets or magnet are called the *field magnets or magnet.*

Connect a dry cell B with the motor as shown in Fig. 1 above. Does the armature revolve?

Disconnect one wire, place the armature in a position parallel to the magnets and move the permanent magnets back. Follow the path of the current: from the carbon pole of the cell to the brush, commutator section, around the armature, to the second commutator section, to the second brush and back to the zinc pole of the cell.

Use the rule for finding the N pole of an electromagnet to find the N pole of the armature. Check this by testing with a compass, with the current flowing through the armature.

Now move the N pole of the armature through $\frac{1}{2}$ turn and test it again with the compass. Is it now a S pole? Why?

Do the armature poles change each half revolution? That is, is each end of the armature a N pole in one half turn and a S pole in the other half turn? Where are the ends of the armature when the change is made?

Connect the cell and notice the direction in which the armature revolves. Reverse the direction of the current. Is the direction the armature revolves reversed? Why?

The field magnet. Connect the cell and notice the direction the armature revolves.

Reverse both magnets. Is the direction the armature revolves reversed? Why?

Reverse one magnet only, to make the ends near the armature either both N or both S. Does the armature revolve? Why?

Make one pole near the armature N and the other S. Move each pole back 2 in. and connect the cell. Does the armature revolve as rapidly when the magnetic field is weakened?

Move the magnets back and attach the electromagnet (field magnet) as shown in Fig. 2; connect the cell and notice the direction the armature revolves.

Use the rule for finding the N pole of an electromagnet to find the N pole of the field magnet. Check this with a compass. Do you understand from this why the armature revolves in the direction it does?

Reverse the direction of the current. Is the direction the armature revolves reversed? Why not? Is it because the current is reversed in both the armature and the field magnet?

Connect the cell and notice the direction in which the armature revolves. Then reverse the direction of the current in the field magnet only, by connecting the field magnet wires to the opposite binding posts. Is the direction in which the armature revolves reversed?

Follow the path of the current from the carbon pole of the cell to the first binding post of the motor. Do you notice that the current divides here and that part of it goes through the armature and part through the field magnet? These parts unite at the second binding post and return to the zinc pole of the cell. When a current is divided in this way each part is called a *shunt* of the other. A motor arranged in this way is called a *shunt wound* motor.

Connect the field magnet as shown in Fig. 3. Follow the path of the current. Do you notice that the current flows through the armature and field magnet one after the other, that is, *in series?* A motor arranged in this way is called a *series wound* motor.

Connect the cell and notice the direction the armature revolves. Reverse the direction of the current. Is the direction the armature revolves reversed? Why not? Is it because the current is reversed in both the armature and the field magnet?

Reverse the direction of the current through the field magnet only, as follows: Disconnect the field magnet wire from the binding post and connect the other field magnet wire to this post. Connect the cell. Is the direction in which the armature revolves reversed? Why?

Exercise 23. Electric Motors.

Examine one or more of the school motors and identify the field magnet, armature, brushes, and commutator, or rings if the motors run on alternating current. Consult page 183, *Physics of the Household.*

Examine the name plate on each motor and learn the voltage for which it is made and the amperage of the current it uses.

Calculate the power of the current in watts and horse power, remembering that: watts = volts × amperes, and that 746 watts = 1 horse power. Consult pages 208–210, *Physics of the Household.*

Calculate the number of 40-watt tungsten lamps which could be lighted with the current used in the motor.

Find the cost of the city current per kilowatt hour and calculate the cost of running each motor for one hour.

Home Exercise.

Repeat this exercise with the electric motor in your home and make a written report.

Exercise 24. Electric Heating and Cooking Appliances.

Examine one of each type of electric heating and cooking appliances in the school and learn as much as you can about how each is heated. Consult pages 187–191, *Physics of the Household.*

Examine the name plate on each to learn the voltage, amperage, and watts of the current used.

NOTE. — In some cases the amperage is given and in others the watts.

Calculate the watts of the current used in each appliance (watts = volts × amperes) and then calculate the number of 40-watt tungsten lamps which could be lighted with the current used in each.

Find the cost of the city current per kilowatt-hour and calculate the cost of running each appliance for 1 hour and for 10 hours. Consult page 209, *Physics of the Household.*

Home Exercise.

Repeat this exercise with the electric heating and cooking appliances in your home and make a written report.

Exercise 25. Electric Lighting.

Trace the path of the electric light wires from the point at which they enter the school, to the switch-box and, if possible, some distance along each branch.

Make a diagram of this part of the lighting circuit and show on it the main switch, the fuses, the meter, the main wires, and the branch wires. Consult page 215, *Physics of the Household.*

Home Exercise.

Repeat this exercise with the electric light wires in your home.

From the price of the city current per kilowatt-hour, calculate the cost per hour of the current used in one electric light in your home.

Make a written report on this work.

NOTE. — Carbon lamps of 16 candle power use electric current at about the rate of 55 watts; tungsten lamps are usually marked 25 watts, 40 watts, 60 watts, etc., according to the rate at which they use current.

Read your electric current meter once each month for six months, record the date and reading and compare your readings with those sent in by the electric light company.

Experiment 27. Electrolysis, Electroplating, and the storage cell.

To study electrolysis and to show how it is applied in electroplating and in the storage cell.

Two tumblers.
Dilute H_2SO_4 (1–60).
Concentrated solution of $CuSO_4$.
One copper strip.
One carbon rod.
Two lead strips.
Electric bell.
Compass.
Two dry cells.
Strip holder.

Electrolysis

Method. Attach two copper wires to a dry cell and dip the clean bare ends in dilute sulphuric acid. Do you notice that bubbles of gas are formed on one end but none at all on the other? Do the bubbles appear on the anode (the way in) or on the cathode (the way out)?

When H_2SO_4 is dissolved in water it breaks up into positively charged H ions and negatively charged SO_4 ions. When a current is passed through this solution the H ions move with the current and are liberated at the cathode (these are the bubbles you see); the SO_4 ions move in the opposite direction and are liberated at the anode. In this case the anode is copper and the SO_4 ions unite with it to form $CuSO_4$, and for this reason no bubbles appear.

Place the bare ends of the copper wire in a concentrated solution of $CuSO_4$. Do you notice bubbles on either the cathode or the anode? After the current has run for one minute examine the cathode and the anode. Which has received a bright covering of copper?

When $CuSO_4$ is dissolved in water it breaks up into positively charged Cu ions and negatively charged SO_4 ions. When a current is passed through this solution the Cu ions move with the current and are deposited on the cathode (this is the bright coating of copper); the SO_4 ions move in the opposite direction and are deposited on the anode as explained above.

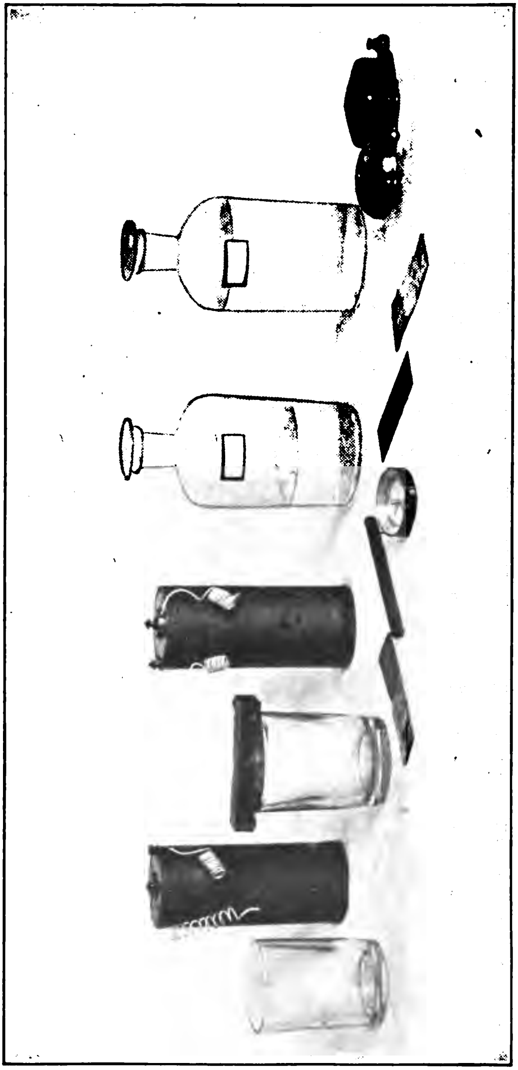

FIG. 32. Apparatus used to illustrate electrolysis, electroplating, and the storage cell.

Electroplating

Place a copper strip and a carbon rod in a concentrated solution of $CuSO_4$; connect the copper plate with the carbon pole of a dry cell and the carbon rod with the zinc pole. Allow the current to run for two minutes and examine the carbon rod.

Note.—In these experiments you must allow the current from the dry cells to run for two and three minutes. This uses up the cells very rapidly and for this reason and others it will be necessary to purchase new dry cells each year.

Is the carbon rod plated with copper?

Reverse the current and allow it to run for two or three minutes. Is the copper removed from the carbon rod?

The Storage Cell

Place two lead plates (1 in. by 4 in.) in dilute sulphuric acid and connect them with two dry cells joined in series. Allow the current to run for three minutes and then disconnect the dry cells and connect the storage cell with an electric bell. Has the storage cell been charged? Consult your text book and answer these questions:

What gases appear at the cathode and anode?

What substances are formed on the cathode and anode when the storage cell is charged?

Direction of charging and discharging currents. Connect the dry cells with the storage cell again for one half minute and with a compass find the direction of the charging current (check by following the wire to the dry cells). Disconnect the dry cells and find the direction of the discharging currents of the storage cell by means of the compass.

Do the charging current and the discharging current flow in opposite directions?

Experiment 28. Measurement of resistance.

To learn how to measure resistance by means of a Wheatstone bridge.

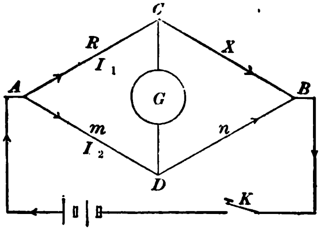

FIG. 33. Diagram illustrating the principle of the Wheatstone bridge.

Two dry cells.
Key.
Wheatstone bridge.
D'Arsonval galvanometer.
Resistance box.
One yard # 30 G. S. wire.

The principle of the Wheatstone bridge is illustrated in Fig. 33. There are four resistances R, X, m, and n. The current from the battery flows to A and divides; one part, I_1, flows through the resistances R and X, and the other part, I_2, through the resistances m and n. The two parts unite at B and flow back to the battery. There is a continual fall in potential from A to B along both branches of the circuit, and if we choose some point C in the branch A, C, B, there must be some point D in the branch A, D, B which is at the same potential as C. If these points C and D are connected through a galvanometer G, there is no current through the galvanometer, because C and D are at the same potential. When these points C and D are found, the ratio of the resistance X to the resistance R is the same as the ratio of the resistance n to the resistance m, or

$$\frac{X}{R} \quad \frac{n}{m} \qquad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \qquad (1)$$

If then R, m and n are known resistances, the resistance of X can be calculated.

The apparatus you will use is illustrated in Fig. 34. Two dry cells are connected through a key *K* to the points *A* and *B*. *R* is a known resistance (a resistance box or a coil of known resistance), *X* is the unknown resistance. ***mDn*** is a piece of #30 German-silver wire 1 meter long stretched over a meter stick. *G* is a D'Arsonval galvanometer with one terminal connected at *C* and with the other terminal *D* free to slide along the wire ***mn***. The resistances of ***m*** and ***n*** are proportional to their lengths, which are read on the meter stick.

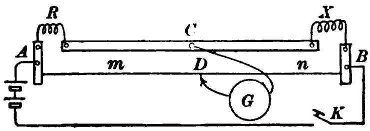

FIG. 34. Diagram of the slide wire bridge used to measure the resistance of wire.

The current from the dry cells enters at *A* and divides. Part of it flows through *R* and *X* and part of it through ***m*** and ***n***. When a point *D* is found such that there is no current through the galvanometer we can calculate *X* by inserting *R*, ***m***, and ***n*** in (1).

Method. Insert 1 yard of #30 German-silver wire at *X* and a resistance box at *R*. Place the sliding point *D* at the 50 cm. mark. Remove the 1 ohm plug from the resistance box *R*, close the key and observe the direction the galvanometer needle turns. Repeat with the 10 ohm plug removed, and if the galvanometer needle turns in the opposite direction you know the resistance is between 1 and 10 ohms. Try plugs between 1 and 10 until the deflection is small and then obtain the point of no deflection by moving *D* back and forth. When this point is found measure ***m*** and ***n*** and the resistance *R*. Insert these values in (1) and calculate *X*.

Measure the resistance of 1 yard of #30 iron wire in the same way.

FORM OF REPORT

	German Silver	Iron
Resistance *R*		
Length of ***m***		
Length of ***n***		
Resistance *X*		

Experiment 29. Resistance measured by voltmeter-ammeter method.

To find the resistance of a number of appliances by the voltmeter-ammeter method.

To find the electrical power used in each appliance.

To find the efficiency of a water heating appliance.

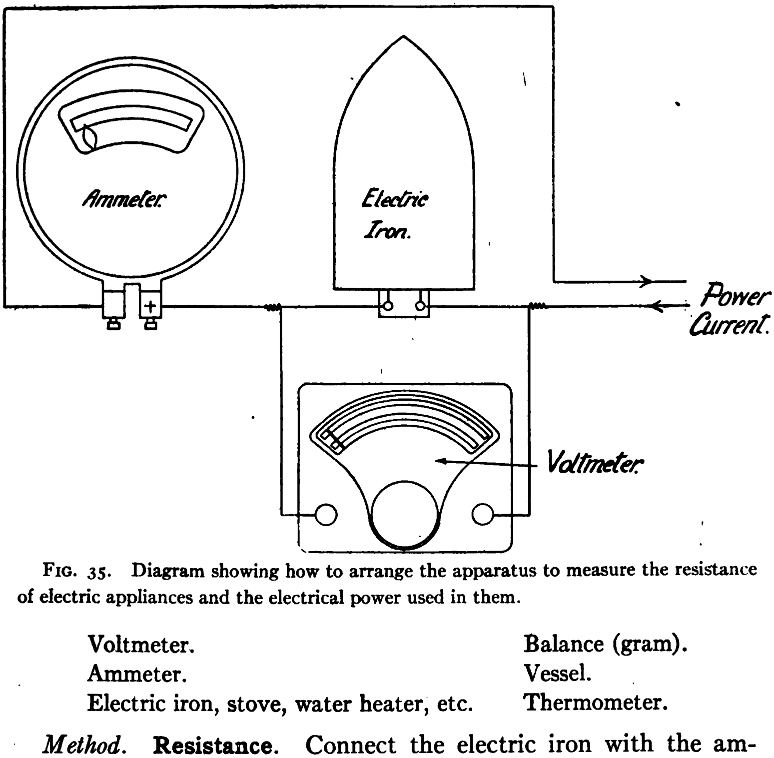

FIG. 35. Diagram showing how to arrange the apparatus to measure the resistance of electric appliances and the electrical power used in them.

Voltmeter.	Balance (gram).
Ammeter.	Vessel.
Electric iron, stove, water heater, etc.	Thermometer.

Method. **Resistance.** Connect the electric iron with the ammeter, voltmeter, and power circuit as shown in Fig. 35. Read the E.M.F. in volts and the current in amperes. Use Ohm's law (amperes = volts ÷ ohms) to calculate the resistance of the iron in ohms. Repeat with the stove.

Power. The electrical power used in any appliance in watts is found by multiplying the current in amperes by the E.M.F. in volts, that is, watts = amperes × volts.

Use the results obtained above to calculate the electrical power used in each appliance.

The efficiency of a water heater. Weigh a vessel of about 1 liter capacity. Multiply this weight by the specific heat of the metal of which the vessel is made (.095 for copper, .11 for iron) to find the number of calories of heat required to warm the vessel 1° C.; this is called the *water equivalent* of the vessel.

Add 500 g. of ice water, insert the water heater and stir with the thermometer continuously, observe and record the exact time when the water is 15° C. below room temperature; also record the exact time when it is 15° C. above room temperature. Record the volts and amperes at the low temperature and at the high temperature.

From the average voltmeter and ammeter readings calculate the power in watts.

Now, by Joule's law, the heat in calories, produced by a current = watts × .24 × seconds. Calculate the heat in calories given by the current to the water heater, = input.

The heat in calories which the water received = (weight of water + water equivalent) × change in temperature. Calculate the number of calories received by the water, = output.

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{calories received by water}}{\text{calories given by current.}}.$$

Calculate the efficiency of the water heater.

FORM OF REPORT

	Volts	Amperes	Resistance	Watts
Iron				
Stove				

	Volts	Amperes	Time
Water heater, beginning .			
Water heater, end . . .			
Average			Difference

Weight of calorimeter = ... g.
Water equivalent of calorimeter = ... g.
Weight of water = ... g.
Water + water equivalent = ... g.
Change of temperature = ... °C.
Calories produced by current =
Calories received by water =
Efficiency =

Experiment 30. Cells connected in series and in parallel.

To find the electromotive force in volts of cells connected in series and in parallel.

Five dry cells. Voltmeter.

Method. Connect one dry cell with a voltmeter. What is the E.M.F. in volts?

Cells in series. Connect two cells in series and connect them with the voltmeter. What is the E.M.F. of two cells in series?

In the same way find the E.M.F. of 3, 4, 5, etc., dry cells joined in series.

Cells in parallel. Connect two cells in parallel and connect them with the voltmeter. What is the E.M.F. of two cells in parallel?

In the same way find the E.M.F. of 3, 4, 5, etc., cells in parallel.

Is the E.M.F. of n cells, in series, equal to n times the E.M.F. of one cell?

Is the E.M.F. of n cells in parallel equal to the E.M.F. of one cell?

FORM OF REPORT

	In Series	In Parallel
E.M.F. of 1 dry cell	volts	volts
E.M.F. of 2 dry cells	volts	volts
E.M.F. of 3 dry cells	volts	volts
E.M.F. of 4 dry cells	volts	volts
E.M.F. of 5 dry cells	volts	volts

Experiment 31. Induced currents.

To study induced currents.

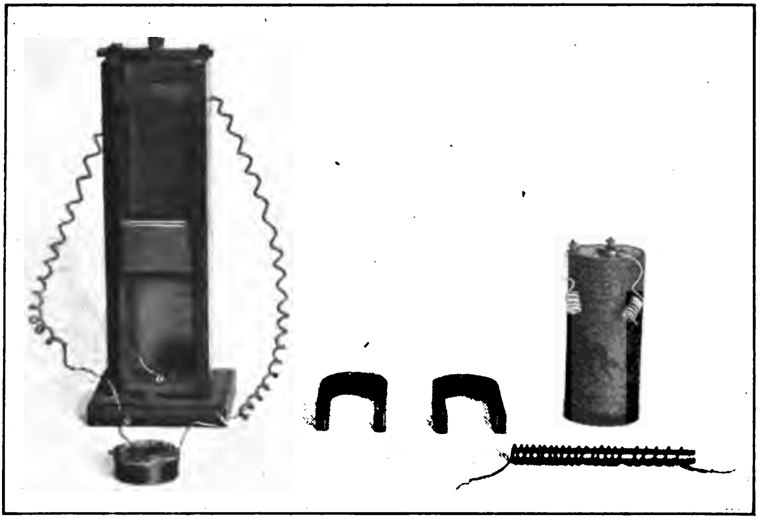

FIG. 36. Apparatus used to illustrate induced currents.

Coil.
D'Arsonval galvanometer.
Two magnets.
Dry cell.
Electromagnet.

Make a coil about 2 in. in diameter by winding about 15 feet of #22 insulated wire about two fingers held apart, and connect it with a delicate galvanometer.

Push the north pole of a permanent magnet into the coil. Is a current produced?

Allow the magnet to remain in the coil. Does the current continue?

Pull the north pole out of the coil. Is there a current produced? In what direction?

Strength of E.M.F. produced in the coil. Push a magnet pole into the coil slowly and then rapidly. Which produces the greater effect?

Hold together the like poles of two magnets and push them into the coil. Is the effect greater than that produced by one magnet pole?

Direction of E.M.F produced in coil. *Lenz's Law* states that *the direction of the current produced by induction is always such that its magnetic field opposes the motion of the thing producing it.*

Test this as follows. In order to know the direction of the induced current in the coil, we must know how the galvanometer needle turns when the current enters the galvanometer through one binding post or the other. To find this, connect the galvanometer with a dry cell (through a high resistance, to avoid damaging the galvanometer), and notice the direction the needle moves. We know the current from the dry cell comes from the carbon pole. By noticing the binding post through which the current from the dry cell enters the galvanometer, and the direction the needle moves, we can afterwards tell the direction of any current which enters the galvanometer.

Connect the coil with the galvanometer. Push the north pole of the magnet into the coil. Is the current produced in the coil in such a direction as to make the top of the coil a north pole (rule, page 74) and thus to oppose the downward motion of the north pole of the magnet?

Pull the north pole of the magnet out of the coil. Is the direction of the induced current in the coil such as to make the top of the coil a south pole, and thus to oppose the upward motion of the north pole of the magnet?

Test the direction of the currents produced by the south pole in the same way.

Induced currents produced by an electromagnet. Find the north pole of an electromagnet (rule, page 74) and push it into the coil. Does it act in the same way as a permanent magnet?

Place the electromagnet in the coil, and then start and stop the current in the electromagnet. Is the effect the same as though the electromagnet were moved into and out of the coil? Is the direction of the induced current in the coil opposite to that in the electromagnet when the current is starting in the electromagnet, and in the same direction when the current in the electromagnet is stopping? Is an induced current produced in the coil when the current in the electromagnet is neither starting nor stopping, but is running steadily?

FORM OF REPORT

How is an induced current produced?

Is the effect greater or less when the magnet is moved quickly? Is the effect greater when two magnets are used?

Make diagrams in your note book showing the direction of the induced current produced in the coil by the magnet. Make two diagrams for the N pole and two for the S pole.

Experiment 32. Applications of induced currents.

To study the magneto, dynamo, and induction coil.

Magneto.	Induction coil.
Dynamo.	Two dry cells.
Motor.	Galvanometer.
Incandescent lamp.	Four spikes for handles.

Iron wire #30.

Let the class be divided into three groups and let each group work one third of the period with each appliance.

MAGNETO

Method. Connect two metal handles to the magneto binding posts by means of wires and let each student in turn hold the handles while another operates the magneto. Can the current be felt?

In order that a current may be felt it is necessary that the electromotive force, in volts, of the current be high. In the text book we learn that the electromotive force of an induced current depends upon: the strength of the magnetic field, the number of turns of wire on the coil, and the speed with which the magnetic lines of force are cut.

Remove the magnets and examine the interior. Is the electromotive force of the induced current high for the following reasons:

(1) a strong magnetic field is produced by four or five strong magnets;

(2) there are many turns of wire on the revolving coil (the armature);

(3) the coil is so geared that it can be revolved rapidly.

Turn the coil without the magnets. Can a current be felt? Why? Replace the magnets and connect the magneto with the 25-turn coil of a galvanometer. Turn the handle slowly and observe whether the current is direct or alternating.

FIG. 37. Showing the magneto, dynamo, and induction coil, and the appliances used to illustrate their action.

DYNAMO

Connect a hand power dynamo with an incandescent lamp of suitable voltage and amperage. Turn the handle and light the lamp. In this case the mechanical energy supplied by your arm is transformed into electrical energy in the dynamo and this in turn is transformed into light and heat energy in the lamp.

While one student is operating the dynamo let another turn the lamp on and off. Is more energy required to drive the dynamo when the light is on than when it is off? Why?

Disconnect the lamp and join the two wires from the dynamo by means of a piece of #30 iron wire about 1 in. long. Operate the dynamo and heat the wire. What are the energy transformations?

If a second similar dynamo is available, connect them and turn the handle of the first dynamo. Does the armature of the second dynamo revolve? Turn the handle of the second dynamo. Does the armature of the first dynamo revolve? What does this illustrate about the construction of a dynamo and a motor?

Connect the dynamo with one or more small motors and operate the dynamo. What are the energy transformations?

Examine the dynamo. Identify the field magnet, armature, commutator, and brushes. Is the dynamo shunt wound or series wound?

INDUCTION COIL

Attach two metal handles to the terminals of the secondary coil of a small demonstration induction coil. Attach one or two dry cells to the primary coil and start the interrupter. Let each student in turn hold the handles while another pulls out the brass reducing tube slowly. Can the current induced in the secondary be felt?

Take the induction coil apart, and identify the primary coil, secondary coil, soft iron core, and interrupter. Follow the path of the current from the battery through the interpreter and the primary coil.

NOTE. — These small coils usually lack a condenser.

Exercise 26. Electric Light Plant.

As a class visit an electric light plant or an electric power plant, *e.g.* street-car power plant. Locate the dynamo and the source of power, that is, boiler and engine or water wheel.

On the dynamo identify the field magnet, armature, brushes, and commutator or rings.

On the switchboard identify the voltmeter, ammeter, and kilowatt meter.

Make a rough diagram showing the location of the source of power, the dynamo, the switchboard, and of the wires to and from the switchboard.

Home Exercise.

Examine the lighting plant on an electrically lighted automobile. Locate the dynamo, the storage battery, the lights, and the wires connecting these.

Make a rough diagram of the plant and make a written report.

Exercise 27. Telephone Exchange.

As a class visit the telephone exchange in your town or city and have the officer in charge explain to you what happens when you ring up central and ask for any number.

Home Exercise.

In your own home follow the telephone wires from the point at which they enter your house to the telephone.

Open your telephone and examine the interior; follow the wire from the battery (if it is a battery telephone) to the transmitter, the induction coil, and back to the battery: follow one line wire to the induction coil, the receiver, and back to the other line wire.

Exercise 28. Wireless Station.

As a class visit the wireless station in your city, if there is one, and ask the operator to explain how the spark is produced, how a message is sent, and how one is received.

Experiment 33. Horse-power and efficiency of an electric motor.

To determine the horse-power and efficiency of an electric motor by means of a Prony brake.

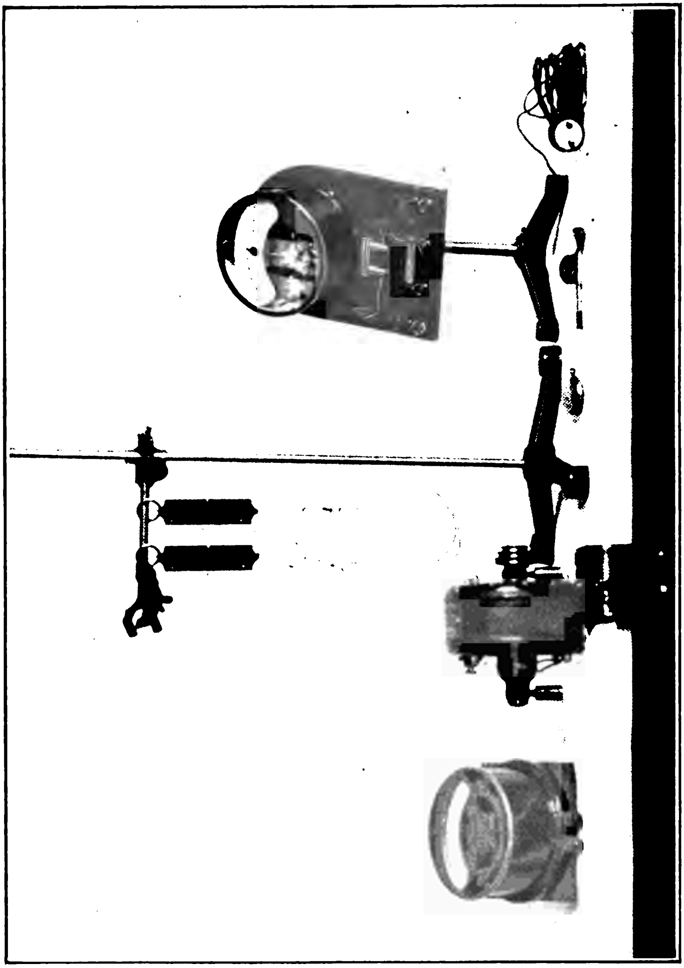

FIG. 38. Apparatus used to measure the horse-power and efficiency of an electric motor.

Motor for 110 or 220 volt current.	Watch.
Voltmeter.	Cord or belt.
Two spring balances.	Speed counter.
Ammeter (0–5 amperes).	Support and large clamp.

Method. Arrange the circuit as shown in Fig. 39; the current flows through the motor *M* and ammeter *A* in series and through the voltmeter *V* and motor in parallel. The Prony brake *B* consists of two spring balances with a cord or belt attached to the hooks. Place the cord under the pulley of the motor and raise the balances until each records about 2 lb.

Horse-power. To determine the horse-power of the motor we must measure:

(1) The number of revolutions per second.

(2) The circumference of the pulley expressed in feet.

(3) The difference in the readings of the brake balances, expressed in pounds, when the motor is running.

It will be remembered that one horse power is the power to do 33000 foot pounds of work per minute, or $33000 \div 60 = 550$ foot pounds of work per second. You will find the number of foot pounds of work the motor does per second and divide this number by 550 to find the horse-power of the motor.

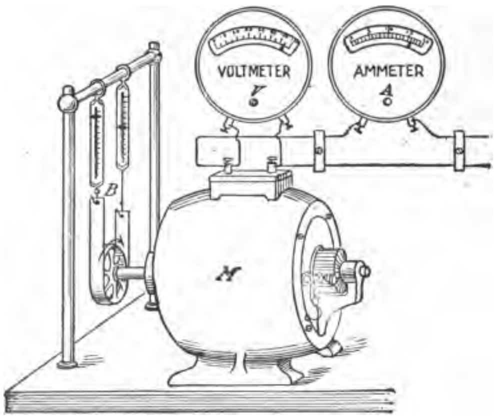

FIG. 39. Diagram showing how to arrange the apparatus.

To find the number of revolutions per second, adjust the brake, then let one student hold the speed counter against the end of the pulley and give to another student the signal when to start keeping time and also announce 1, 2, 3, etc., to 10, at the end of each 100 revolutions. In this way find the number of seconds required to make 1000 revolutions and from this calculate the number of revolutions per second.

To find the brake load in pounds, read each balance in ounces when the motor is running and divide the difference by 16.

To find the circumference of the pulley in feet, pass a cord around the pulley four times; measure the length of the cord in inches, divide the result by four and then by twelve.

Calculate the horse-power of the motor as follows: The brake load in pounds multiplied by the circumference of the pulley in feet gives the foot pounds of work done by the motor in one revolution. This multiplied by the number of revolutions per second gives the foot pounds of work done by the motor in one second. This number divided by 550 gives the horse-power of the motor.

$$\text{H. P.} = \frac{\text{Load in lb.} \times \text{circ. in ft.} \times \text{revolutions per second}}{550}.$$

Efficiency. The efficiency of any machine is equal to the *output* divided by the *input*. You have just found the *output* in horse-power. You must now find the *input* in horse-power. It will be remembered that a rate of working of 746 watts = 1 horse-power. To find the *input*, then, read the fall in potential in the motor in volts and the number of amperes used by the motor. The product of these equals the watts, or the rate at which electric energy is supplied to the motor. This number divided by 746 gives the horse-power supplied.

$$\text{H. P.} = \frac{\text{volts} \times \text{amperes}}{746} = \text{input.}$$

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} =$$

Make the load greater and determine again the output, input, and efficiency. Is the efficiency greater or less on the heavier load?

FORM OF REPORT

Revolutions per second		
Brake load, lb.		
Circumference of pulley, feet		
Horse-power, output		
Fall in potential, volts		
Current, amperes		
Horse-power, input		
Efficiency		

LIGHT

Experiment 34. The photometer.

To determine the candle power of an oil lamp, a 16 candle power incandescent carbon lamp, and a 40 watt tungsten lamp.

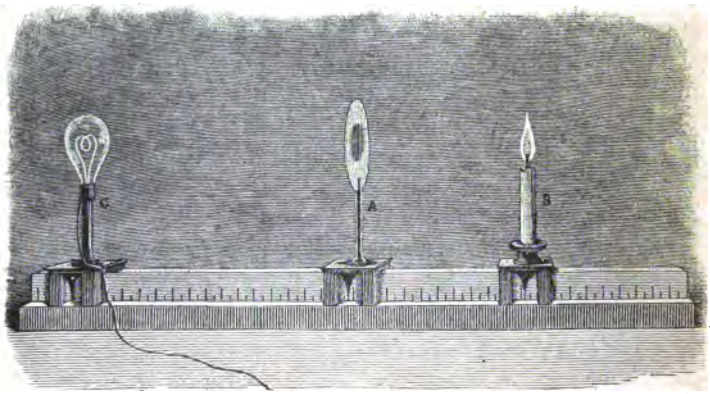

FIG. 40. Illustrating the photometer.

Bunsen photometer in dark room or in light-proof box.	Carbon lamp, 16 cp.
	Tungsten lamp, 40 watt.
Ordinary oil lamp.	Candle.

The *candle power of a lamp* is *the ratio of the amount of light given by the lamp to the amount given by a standard candle*, that is, it is the number of times the light given by the lamp is greater or less than that given by a standard candle.

In this experiment you will learn simply the method of finding the candle power of a lamp. Your results will not be exact unless you use a standard candle or a standard lamp.

Method. **Oil lamp**. Arrange the Bunsen photometer as shown in Fig. 40. Place the candle B at one end of the photometer and an ordinary oil lamp at the other; then move the grease spot screen A back and forth until the central spot and the surrounding paper are equally illuminated. When this point is found we know that the screen is receiving the same amount of light on one side, from the lamp, that it is on the other side, from the candle.

Since the intensity of the light from any source varies inversely as the square of the distance between the source and the object illuminated, we can say:

$$\frac{\text{candle power of lamp}}{\text{candle power of candle}} = \frac{(\text{distance from lamp to screen})^2}{(\text{distance from candle to screen})^2}.$$

Measure the distance from the lamp to the screen and from the candle to the screen, then assume that the candle power of the candle is 1 and calculate the candle power of the lamp.

Carbon and tungsten lamps. In the same way find the candle power of the carbon lamp and of the 40 watt tungsten lamp.

Assuming that the 16 candle power carbon lamp uses 55 watts and the tungsten lamp 40 watts, calculate the watts required per candle power for each.

Which light is the more economical?

FORM OF REPORT

	Oil Lamp	Carbon Lamp	Tungsten Lamp
Lamp to screen	cm.	cm.	cm.
Candle to screen	cm.	cm.	cm.
Candle power			

The carbon lamp requires watts per candle power
The tungsten lamp requires watts per candle power

Exercise 29. Lighting.

Make a rough diagram of one class room in your school showing how the light is admitted.

NOTE. — The light should be admitted from the left and rear of a student seated at his desk; it should not be admitted from the front, because then it will shine directly into the student's eyes.

Make a rough diagram of your school kitchen showing where you would hang the electric lamps with relation to the table, range, and sink, to light the kitchen properly at night. Consult page 247, *Physics of the Household.*

Home Exercise.

Make a diagram of your home kitchen showing where you would place the lights if you were consulted.

Make a diagram of your living room showing how you would place the lamps for convenience in reading.

Make a written report.

Experiment 35. Reflection of light.

To show that the angle of reflection is equal to the angle of incidence and that an object and its image are equally distant from the mirror.

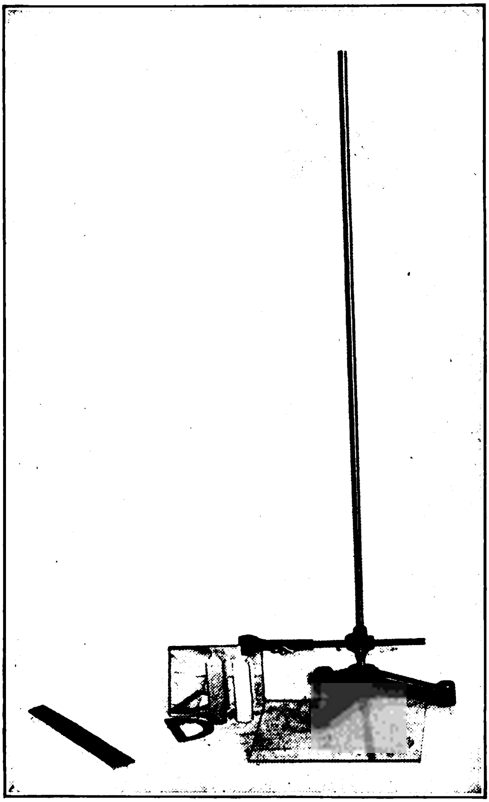

FIG. 41. Apparatus used to illustrate the reflection of light.

Thin mirror.
Plain glass plate.
Pins.
Protractor.
Paper.
Ruler.
Two candles.

The angle of reflection equals the angle of incidence. *Method.* Draw a line on a piece of paper and mark it "mirror line." Stand a thin mirror on this line, perpendicular to the paper.

Stick two pins upright in front of the mirror in a line at an angle of about 45° to the mirror line. Number these pins 1 and 2. Now set up two pins in front of the mirror and exactly in line with the images of pins 1 and 2. Mark these pins 3 and 4. Remove the mirror and pins and draw a line through the pin holes 1 and 2 to the mirror line and a line through the pin holes 3 and 4 to the mirror line. These lines should meet at the mirror line.

At the point of intersection of the lines draw a line perpendicular to the mirror line. Measure the angle between the line 1 2 (the line of incidence) and the perpendicular, and the angle between the line 3 4 (the line of reflection) and the perpendicular. Is the angle of reflection equal to the angle of incidence?

Repeat this with a different angle of incidence.

Distance of image and object. *Method* 1. Draw a line on a piece of paper and mark it "mirror line." Place the mirror on this line perpendicular to the paper. Place a pin in front of the mirror and about 15 cm. from it. With a ruler aim at the image of this pin from two positions on each side of the pin and draw lines to show the positions of the ruler.

Remove the mirror and continue the lines solid to the mirror line and as dotted lines beyond it. The place at which the dotted lines meet is the position of the image. Measure the perpendicular distance of image and object from the mirror line. Are they equal?

Method 2. Draw a line on a piece of paper and place a piece of *plain window glass* on the line perpendicular to the paper. Use two candles of about the same size. Light one and place it in front of the glass, then place the unlighted one behind the glass in such a position that the unlighted candle and the image of the lighted candle coincide when viewed from any point in front of the glass.

The unlighted candle then gives the position of the image of the lighted candle. Measure the distance of each candle from the mirror line. Are they equal?

FORM OF REPORT

	1ST EXP.	2D EXP.
Angle of reflection		
Angle of incidence		

	PIN	CANDLES
Distance of image from mirror		
Distance of object from mirror		

Experiment 36. Index of refraction of glass.

To find the index of refraction of glass.

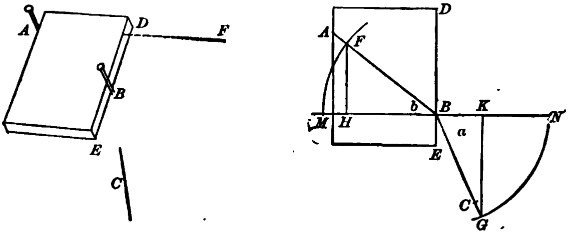

FIG. 42. Diagram of the apparatus used to measure the index of refraction of glass.

Plate glass with parallel edges.	Paper.
Ruler.	Pins.
Compass.	

The *index of refraction of glass* is *the ratio of the speed of light in air to its speed in glass.* You cannot measure the speed of light in air or glass with the apparatus at hand, but the index of refraction of glass is also *the ratio of the sine of the angle of incidence in air to the sine of the angle of refraction in glass,* and these you can measure.

Method. Draw a line on a piece of paper and mark it "plate line"; place the plate glass flat on the paper with one edge exactly along this line. Place one pin at some point *A*, Fig. 42, and another at a point *B*. With a ruler sight through the glass from *B* to the image of *A* and draw a line *C* on the paper along the edge of the ruler.

Remove the glass plate and draw a line *BA*, and a line *MBN* perpendicular as to the plate line from the point *B*. Draw a circle with *B* as center and draw the lines *GK* and *FH* perpendicular to *MBN*.

You must remember that you see the image of the pin *A* in the glass because light starting from *A* passes through the glass to *B* and then through the air to your eye at *G*. You notice that the image of A in the glass is in a new position. The reason for this is that the light which travels from A through the glass to B is bent away from the perpendicular MBN when it enters the air at B. The light when in glass makes an angle b with the perpendicular MBN and when in air makes the larger angle a. To prevent confusion, the angle a in air is always called the angle of incidence, and the angle b in the other medium (in this case glass) is always called the angle of refraction. The index of refraction of glass is sine $a \div$ sine b. Sine a is GK/GB and sine b is FH/FB, but since $GB = FB$ (radii of the same circle) $\frac{\text{sine } a}{\text{sine } b} = \frac{GK}{FH}$ = index of refraction.

Measure GK and FH carefully and calculate the index of refraction of glass.

The index of refraction of glass is also, as stated above, the ratio of the velocity of light in air to its velocity in glass.

FORM OF REPORT

Length of GK = cm.
Length of FH = cm.
Index of refraction of glass =

Experiment 37. Focal length and conjugate foci of a converging lens.

To find the principal focal length and a number of conjugate foci of a converging lens.

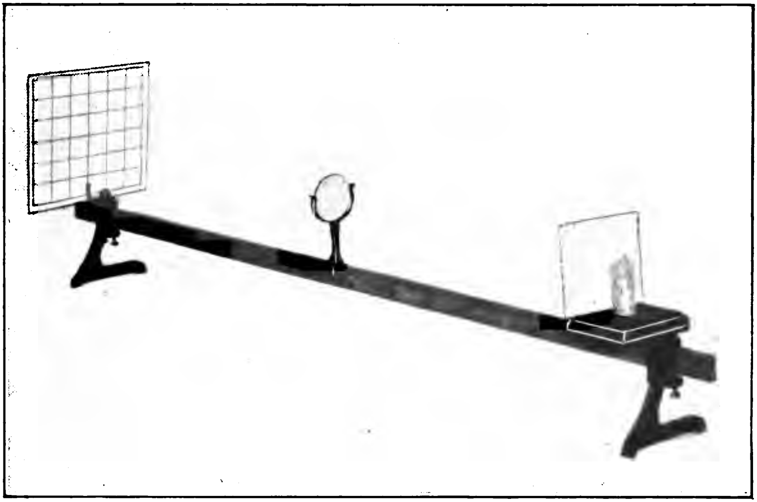

FIG. 43. Apparatus used to measure the principal focal length of a converging lens and to find pairs of congugate foci of the lens.

Meter stick and supports.	Candle or lamp.
Wire netting screen.	Holders.
White cardboard screen.	Lens about 15 cm. focal length.

PRINCIPAL FOCAL LENGTH

The *principal focus* of a lens is *the point at which rays parallel to the principal axis of the lens converge.* When an object is 50 feet or more from a small lens the rays from the object which fall upon the lens are practically parallel, and the image of the object is at the principal focus.

Method 1. Place the lens, in its holder, at one of the principal divisions of the meter stick and place the cardboard screen behind it. Go to the back of the room and point the lens toward an object outside the window. Move the screen back and forth until the most distinct image is found. Measure the distance between the lens and the screen. This distance is the principal focal length of the lens.

Method 2. If the sun is shining, point the lens at the sun and move the screen back and forth until you find the smallest and brightest image of the sun. Measure the distance between the lens and the screen. This distance is the principal focal length.

Conjugate Foci

The meaning of conjugate foci may be illustrated as follows: if an object is placed at some point *O* in front of a lens and its image is formed on a screen at some point *I* behind the lens, then *O* and *I* are conjugate foci, because if the object is placed at *I* its image will be formed at *O*. There is an infinite number of pairs of conjugate foci.

Method. Arrange the apparatus as shown in Fig. 43. The object, a wire netting illuminated from behind by a candle, gas lamp, or electric light, is at one end of the meter stick; a white cardboard screen, to receive the image, is near the other end; and the lens is between the two.

Move the lens back and forth until the most distinct image of the netting is formed on the screen. Now interchange the illuminated wire netting and the cardboard screen without moving the lens. Do you find that a distinct image is again formed?

Two interchangeable points of this kind are called conjugate foci of the lens. If the object is placed at the first point the image is formed at the second, and if the object is placed at the second point, the image is formed at the first.

Move the screen to a new position and find a second pair of conjugate foci.

To find the principal focus from the conjugate foci. The following equation gives the relation between the conjugate foci and the principal focus:

$$\frac{1}{Do} + \frac{1}{Di} = \frac{1}{F}.$$

In this equation *Do* is the distance of the object from the lens, *Di* is the distance of the image from the lens, and *F* is the principal focal length.

Find a pair of conjugate foci and measure *Do* and *Di*, put these numbers in the equation above and calculate *F*, the principal focal length.

FORM OF REPORT

Principal focal length (1) = cm.; (2) = cm.
Conjugate foci (1) = cm. and cm.
(2) = cm. and cm.
Do = cm. *Di* = cm. *F* = cm.

Experiment 38. Size of real image formed by a converging lens. To show that the size of the image is to the size of the object as *Di* is to *Do*.

Meter stick and supports.
Lens.
White cardboard screen.
Wire netting.
Candle or lamp.
Meter stick.

Method. Arrange the apparatus as shown in Fig. 43. Place the wire netting and lens a certain number of centimeters apart, say 20, and move the screen until a distinct image is formed.

We wish to show that the size of the image is to the size of the object as *Di* is to *Do*. That is, if the distance of the image from the lens is 2, 3, $\frac{1}{2}$, $\frac{1}{3}$, etc., times the distance of the object from the lens, then the size of the image will be 2, 3, $\frac{1}{2}$, $\frac{1}{3}$, etc., times the size of the object.

Measure *Di*, the distance the image is from the lens, and *Do*, the distance the object (the wire netting) is from the lens. To find the size of the image measure the number of millimeters covered by 10 squares of the image of the wire netting. To find the size of the object, measure the number of millimeters covered by 10 squares of the wire netting itself.

Find: $\frac{Di}{Do}$, and $\frac{\text{Size of image}}{\text{Size of object}}$. Are they equal?

Repeat twice with the netting in a new position each time.

FORM OF REPORT

	1	2	3
Distance of image *Di*	cm.	cm.	cm.
Distance of object *Do*	cm.	cm.	cm.
Size of image	mm.	mm.	mm.
Size of object	mm.	mm.	mm.
$\frac{Di}{Do}$			
$\frac{\text{Size of image}}{\text{Size of object}}$			

Experiment 39. Magnifying power of a lens used as a simple microscope.

To show that the magnification produced by a converging lens is equal to *Di* ÷ *Do*.

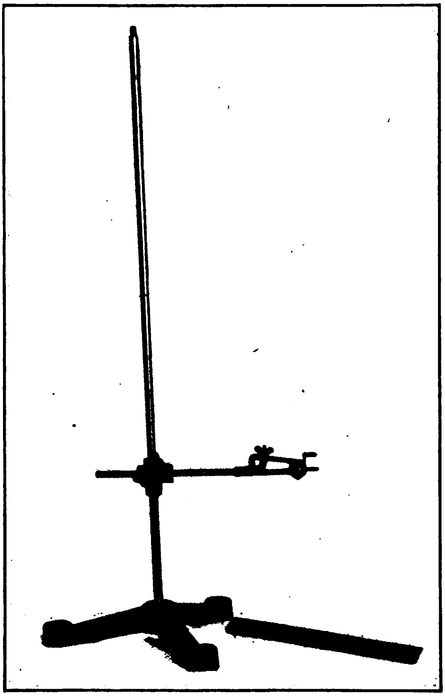

FIG. 44. Apparatus used to measure the magnifying power of a simple microscope.

Converging lens (f. = 2.5–5 cm.).
Black screen with square hole.
(A linen tester instead of the above.)
Scale, mm.
Meter stick.

Method. Place a mm. scale on the table and support the lens just 25 cm. above the scale. Beneath the lens support a black screen with a square hole about 10 mm. on each side, and adjust it until the edges of the hole appear distinct when viewed through the lens. (A linen tester has lens and black screen with square hole.)

Look through the lens with one eye and look at the scale (without the lens) with the other eye. Find the size (on the scale) of the image of the hole. Measure the distance *Do* of the object (the black screen) from the lens.

The mm. scale is placed 25 cm. from the lens (and from the eye) because this is the distance at which the average eye sees things of this size most distinctly.

You have now:

(1) The size of the object = the size of the hole, in mm.

(2) The size of the image = the size of the image of the hole, in mm.

(3) The distance *Do* of the object = the distance between the square hole and the lens, in cm.

(4) The distance *Di* of the image = 25 cm.

Find the magnification = size of image ÷ size of object. Is this equal to *Di* ÷ *Do*?

FORM OF REPORT

Size of Image =	mm.	*Di* =	cm.
Size of Object =	mm.	*Do* =	cm.

Magnification $= \frac{Di}{Do} =$ Magnification $= \frac{\text{Size of Image}}{\text{Size of Object}} =$

Exercise 30. Light Appliances.

Examine the following light appliances in the school: mirror, camera, projection lantern, stereoscope.

Mirror. Look at your image and explain why it is reversed; that is, why your right hand appears to be your left in the image, and vice versa. Explain also why your image is always as far behind the mirror as you are in front. Consult page 254, *Physics of the Household.*

Camera. Measure the focal length of the camera lens, and calculate where the image will be formed when the object is at different distances in front of the lens. Consult Experiment 37 above. The plate or film should be placed at these calculated distances.

Projection Lantern. Measure the focal length of the projection lens, and calculate where the image will be formed when the lantern slide is at different distances behind the lens. Consult Experiment 37 above. The calculated position of the image is where the screen should be placed to get the best image.

Stereoscope. Examine this and explain why the two pictures appear as one, and why the object appears to stand out. Consult page 268, *Physics of the Household.*

Home Exercise.

Repeat these exercises with any of the above appliances which you have in your home.

Make a report of your experiments.

Experiment 40. The astronomical telescope.

To show that the distance between the lenses in an astronomical telescope, when used to view a distant object, is approximately equal to the sum of the principal focal lengths of the lenses; and to show that the magnifying power is equal to the focal length of the objective divided by the focal length of the eye-piece.

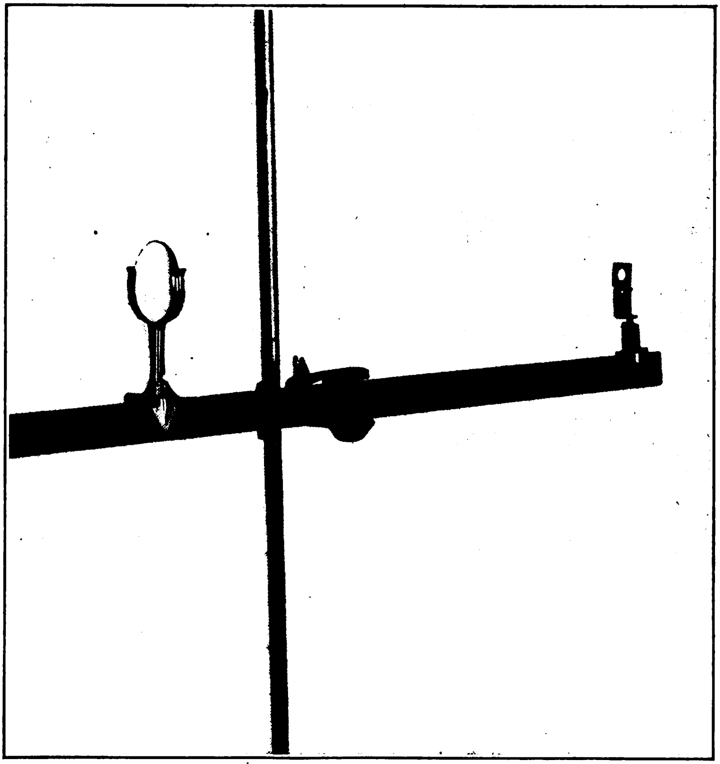

FIG. 45. Apparatus used to illustrate properties of an astronomical telescope.

Lens (f. = 10–15 cm.).
Lens (f. = 2.5–5 cm.).
Meter stick and supports.

Method. **Length of telescope.** Arrange the apparatus as shown in Fig. 45. Make the large lens used in Experiments 37 and 38 the objective and the small lens used in Experiment 39 the eye-piece. Go to the side of the room farthest from the window and focus this rough telescope through the open window on some distant object. Measure the distance between the lenses. Is it equal to the sum of the focal lengths of the lenses? Find these focal lengths again if necessary.

Magnifying power. Draw two parallel lines, 15 cm. apart, on the blackboard and look at them through the telescope from the other side of the room. When the telescope is properly focused, open the other eye and direct another student where to draw two lines on the board which coincide with the image. Measure the distance between the image lines and divide them by the distance between the object lines to find the magnification. Is this magnification equal to the focal length of the objective lens divided by the focal length of the eye-piece lens?

FORM OF REPORT

Focal length of objective lens	= . . . . cm.
Focal length of eye-piece lens	= . . . . cm.
Distance between lenses when viewing a distant object	= . . . . cm.
Distance between image lines	= . . . . cm.
Distance between object lines	= . . . . cm.
Magnification	= . . . .
Focal length of objective ÷ Focal length of eye-piece	= . . . .

Experiment 41. Refraction and dispersion of light by a prism. To show how a ray of light is bent or refracted, and how white light is spread or dispersed, in passing through a prism.

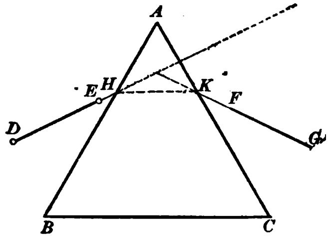

FIG. 46. Diagram of the apparatus used to show how light is bent or refracted.

Glass prism, 60° angles.	Paper.
Pins.	Candle.

REFRACTION

Method. Place the prism *ABC* on a sheet of paper and draw a line along each edge. Place two pins *DE*, Fig. 46, in a line, making an angle of about 45° with one edge. With a ruler sight through the prism at the images of the two pins and draw a line *FG*. Remove the prism and pins and draw the lines *DEH*, *KFG*, and *HK*. The path of the light is *DEHKFG*. At what two points is the light bent or refracted? Make a drawing of this in your note book.

DISPERSION

Method. If the sun is shining, support a prism in such a position, Fig. 47, that the sunlight falls on one edge. Catch the light which passes through the prism on a piece of white paper placed on the table or on the floor. Place between the sunlight and the prism a piece of black cardboard with a slit 2 mm. wide. Is the white light of the sun spread or dispersed into a colored band (the spectrum)? Which colors do you recognize? Which color is least refracted, that is, which is nearest the upper angle of the prism? Which color is most refracted, that is, which is nearest the base of the prism?

Make a drawing in your note book showing the path of the sunlight before and after it passes through the prism.

FIG. 47. Showing how the prism is arranged to illustrate the dispersion of light.

Light a candle and look at it through the prism. Is the flame colored? Which colors now appear the least and the most refracted?

You will notice that these colors are just opposite to those found above. The reason is that the eye sees any object in the direction in which the light from that object enters the eye. In this case the white light is dispersed, the red end of the spectrum being least refracted and the blue end most; but the lines along which the red light and blue light enter the eye are diverging, and if they are extended back they cross at a point in front of the image; therefore the red appears to be the most refracted and the blue the least.

SOUND

Experiment 42. Velocity of sound.

To measure the velocity of sound in air.

Two revolvers.	Blank cartridges.
Two stop watches.	Thermometer.

Method. On a calm day, divide the class into two sections and supply each section with a revolver, blank cartridges, and a stop watch. Let the sections stand a measured distance apart, say ½ mile. If the wind is blowing the sections should stand in line with the wind, if possible. Let the first section make five measurements of the time it takes sound to travel the measured distance as follows: One member has the stop watch and when ready asks a second member to wave a handkerchief. A member of the second section then fires the revolver in the air and the member of the first section with the stop watch measures the time between seeing the flash and hearing the sound. After the first section has made five measurements, let the second section make five in the same way. Take the average of the ten measurements as the time it takes sound to travel the measured distance, and calculate the velocity of sound per second.

This method gives only approximate results, but furnishes an excellent illustration of the velocity of sound in air. The velocity of sound in air is 1087 feet (or 331 meters) per second at 0° C., and it increases about 2 feet (or 0.6 meter) per second for each degree centigrade increase in temperature.

FORM OF REPORT

Temperature of air	= . . . . °C
Distance between divisions	= . . . .
Average time	= . . . . sec.
Velocity of sound per sec.	= . . . .

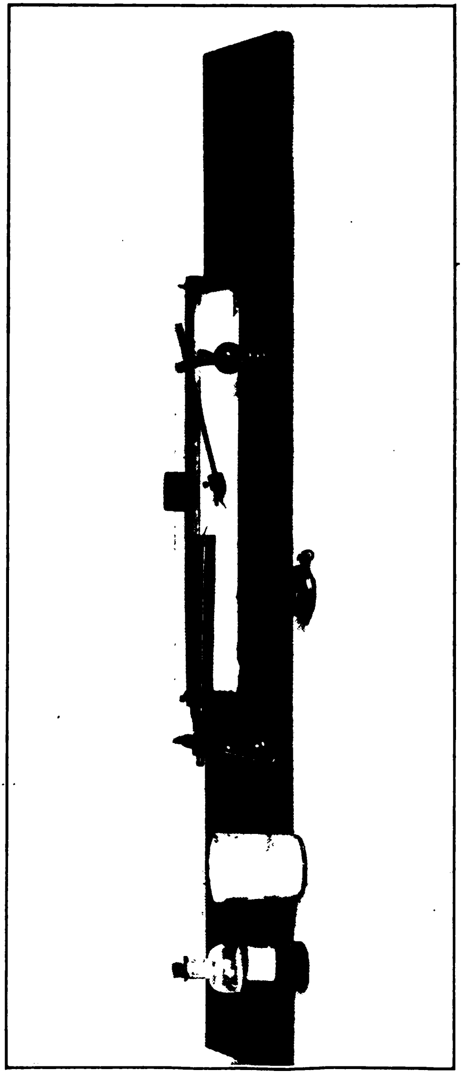

FIG. 48. The apparatus used to determine the number of vibrations per second of a tuning fork.

Experiment 43. Number of vibrations of a tuning fork.

To find the number of vibrations a tuning fork makes per second.

Tuning fork.	Paint (whiting and alcohol).
Recording apparatus.	Sponge.
Watch.	

One vibration of a tuning fork consists of a *complete to and fro motion;* we wish to determine how many of these a fork makes per second. The number is so great that it cannot be determined by the unaided eye and it is necessary to employ some such appliance as is illustrated in Fig. 48. This consists essentially of: a pendulum with a light stylus on the end; the fork with a light stylus on one prong; and a glass plate which can be moved under the pendulum and the fork.

Method. Find the time it takes the pendulum to make 50 vibrations and calculate the number of vibrations per second (a vibration is a complete to-and-fro motion). Make three determinations and take the average.

Cover one side of the glass plate with a mixture of whiting and alcohol by means of a small sponge.

Place the plate under the pendulum and fork and adjust these so that the styluses touch the glass lightly.

Start the fork and the pendulum vibrating and move the plate lengthwise. If your adjustments are correct you will obtain a trace resembling that shown in Fig. 49.

FIG. 49. Illustrating the traces of the fork and of the pendulum.

Calculate the number of vibrations of the fork per second as follows:

The marks *A* and *C* or *B* and *D* each represent those made at the beginning and end of one vibration of the pendulum. Count the number of vibrations (hills on one side only) of the fork between three such spaces as *A* to *C* or *B* to *D*, estimating each to tenths of a vibration. Multiply this by the number of vibrations the pendulum makes in one second. The product is the number of vibrations the fork makes per second.

FORM OF REPORT

	1	2	3	AVERAGE
Time of 50 vibrations of the pendulum =				
Vibrations of the fork in one pendulum vibration = ...				
Vibrations of pendulum per second . =				
Vibrations of fork per second . . . =				

Experiment 44. Wave length of sound.

To measure the length of the sound waves produced by a tuning fork and to measure the velocity of sound in air indirectly.

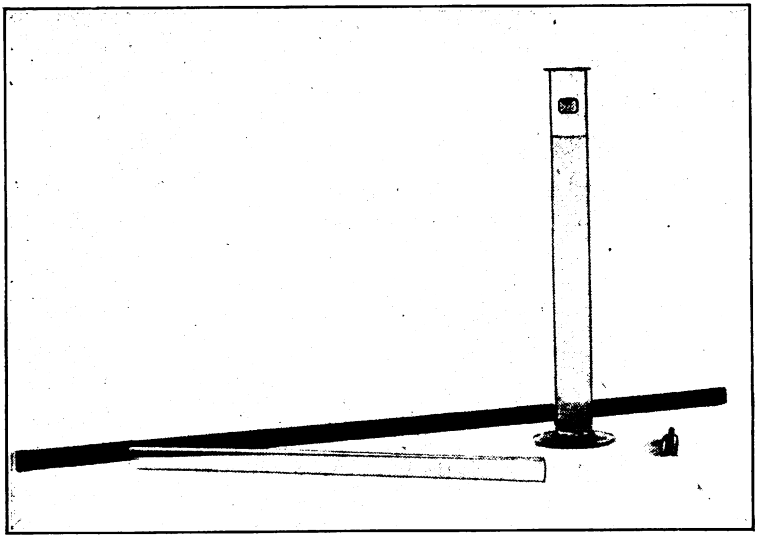

FIG. 50. Apparatus used to measure the length of the sound waves produced by a tuning fork and to measure the velocity of sound indirectly.

Tuning fork ($n = 512$).
Hydrometer jar 18″ deep.
Resonance tube 20″ long.
Meter stick.
Two rubber bands.

WAVE LENGTH

Method. Fill the hydrometer jar with water and place the resonance tube in it. Sound the tuning fork by striking it on a large flat cork or on a piece of heavy rubber tubing, and hold it over the resonance tube. Raise the resonance tube slowly and find the length of air column which gives the loudest sound. Mark this length by means of a rubber band. Repeat until you are sure you have the exact length. Raise the resonance tube and find a longer air column which gives a loud sound. Mark this with a rubber band. Repeat until you have the exact length.

The length of the short air column is approximately equal to one fourth the wave length of the sound. The difference between the lengths of the two air columns is equal to one half the wave length of the sound given out by the fork. Measure the distance between the two rubber bands and multiply it by 2 to obtain the length of the sound wave.

Velocity of Sound

You have found the length of each sound wave given out by the fork. Now since the fork makes 512 complete vibrations per second, it sends out 512 waves each second, and since each wave moves continuously at the same velocity, the product, 512 × wave length, is equal to the distance the sound moves in air in one second, that is, it is equal to the velocity of sound in air per second.

Multiply the wave length found above by 512 to find the velocity of sound per second at the temperature of the laboratory.

FORM OF REPORT

Distance between rubber bands	= . . . . cm.
Wave length	= . . . . cm.
Velocity of sound per sec.	= . . . . cm.
Temperature	= . . . . °C.

Experiment 45. Vibrating strings.

To show that the vibration frequency varies inversely as the length of the wire, and that the notes of an octave are produced by lengths of wire which are in the ratio of 1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$.

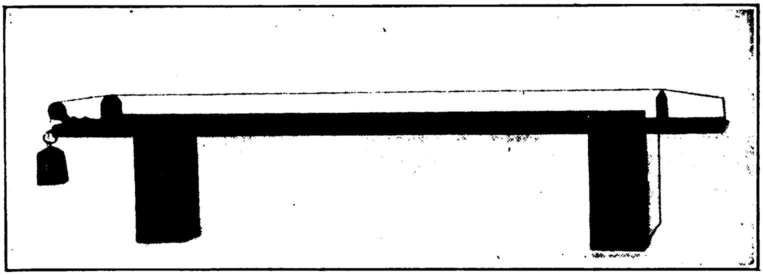

FIG. 51. A simple sonometer.

Sonometer.	Meter stick.
Sonometer wire.	Chalk.

In your class work you have learned that the pitch of a note depends upon the number of vibrations per second of the instrument producing it; for example, the number of vibrations per second required to produce a note one octave higher than a given note is twice as great as the number required to produce the given note.

Method. **Vibration frequency varies inversely as the length.** Stretch a piano wire on a sonometer and adjust the bridge until the wire is a definite length (between 80 cm. and 100 cm.). Mark on the sonometer lengths $\frac{1}{2}$ and $\frac{1}{4}$ of the length of the string.

Sound the note, then move the bridge until the length of the wire is $\frac{1}{2}$ and sound it again. Is the second note one octave higher than the first note?

Move the bridge until the length of the wire sounded is $\frac{1}{4}$ the length of the first, that is, $\frac{1}{2}$ the length of the second. Is the third note one octave higher than the second? Does the vibration frequency vary inversely as the length of the wire?

The notes of an octave. Stretch the wire and adjust the bridge until the length of the wire is just 90 cm. On the board of the sonometer mark lengths equal to 1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, and $\frac{1}{2}$ of the 90 cm. Sound the wire at the 90 cm. length and then move the bridge to each of the shorter lengths in turn and sound the wire. Are the notes produced those of an octave?

ADVANCED MECHANICS

Experiment 46. The parallelogram law.

To illustrate the parallelogram law.

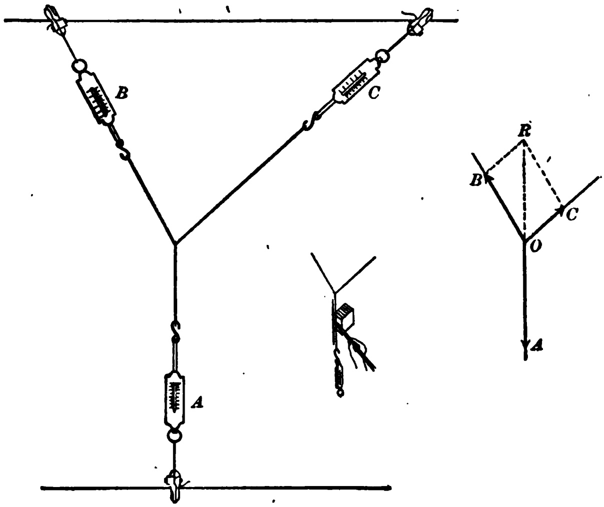

FIG. 52. The apparatus used to illustrate the parallelogram law.

Three spring balances.
Large sheet of paper.
Ruler.
Three small clamps.

The *parallelogram law of forces* is: *If two forces acting at an angle upon a point are represented in direction and amount by straight lines, the resultant of the two forces is exactly represented in direction and amount by the diagonal of the parallelogram of which the lines are the sides. The equilibrant is equal to the resultant, but is in the opposite direction.*

Method. Attach a stout cord to the ring of each balance. Connect the hooks of two balances by means of a piece of strong fish line about 30 cm. long. Attach the hook of the third to the middle of this line by means of a piece of fish line about 15 cm. long.

Attach the balances to clamps so placed that the cords are over a piece of paper or a page of your notebook in the relationship shown in Fig. 52, having one balance at *C*, one at *B*, and one at *A*.

Pull the balance *A* in order to stretch each balance. Mark carefully the point *O* and draw a short line under each cord in the manner illustrated in the middle figure. Mark beside each line the number of ounces (or pounds) pull on the corresponding balance.

Remove the balances and draw the lines *OC*, *OB*, and *OA*, making their lengths equal to the number of ounces (or pounds) pull on the corresponding balances, according to any convenient scale ($\frac{1}{4}$ in. = 1 ounce, etc.).

On the lines *OC* and *OB* construct a parallelogram. Then measure the length of the diagonal *OR* and calculate the force it represents. This is the resultant. Is it equal to the equilibrant represented by *OA*? Is the resultant represented in direction and amount by the diagonal of the parallelogram?

Experiment 47. Efficiency of a machine.

To determine the efficiency of a commercial block and tackle.

Block and tackle.
Weights.
Spring balance.
Yard stick.

A *machine* is *any contrivance by means of which a force applied at one point exerts a pressure or a pull at another point.*

The *efficiency of any machine* is *the ratio of the work done by the machine to the work put into it*, that is,

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}.$$

The *law of machines* is: *If there is no friction, the weight times the distance the weight moves* (*output*) *is equal to the force times the distance the force moves* (*input*).

In all actual machines there is friction, that is, a force which resists motion. This friction is due to the roughness of the bearings, the stiffness of belts or ropes, and to other causes. In an actual machine, then, force is required to overcome friction and therefore the input is always greater than the output. In many machines work also must be done to move parts of the machine (for example, to lift the lower block of this block and tackle). This is classed as useless work, since it helps to make the input greater than the output.

Method. Support the upper block in a suitable manner and attach a weight of 10 lb. to the lower block. Find the force in pounds required to raise the weight slowly.

Lower the weight until it is just touching the floor; mark the position of the spring balance and measure the distance the force (the balance) moves to raise the weight 1 foot.

Calculate the work in foot pounds done by the machine in raising the weight 1 foot = weight × distance weight moves = 10 × 1 = 10 foot pounds = output.

Calculate the work in foot pounds put into the machine =

force × distance force moves in raising weight 1 foot = input. Calculate the efficiency = output ÷ input.

Attach a weight of 20 lb. to the lower block and find the force in pounds required to raise it slowly. Calculate the output, input, and efficiency.

Repeat with a weight of 30 lb.

Does the efficiency of the machine increase with the weight?

FORM OF REPORT

	Weight	Output	Force	Input	Efficiency
1	lb.	ft. lb.	lb.	ft. lb.	%
2	lb.	ft. lb.	lb.	ft. lb.	%
3	lb.	ft. lb.	lb.	ft. lb.	%

If the block and tackle is not available use the small laboratory pulleys (see Fig. 9), and use weights of 200 g., 400 g., and 600 g. Measure the input and output in gram centimeters.

Experiment 48. Accelerated motion.

To show that the space a body falls varies as the square of the time and that the velocity of fall is independent of the weight of the body.

To find the velocity of a projectile.

Pebbles. Watch.

The formula for finding the space a body falls from rest is $s = \frac{1}{2} gt^2$. Where s is the distance the body falls, g the constant of acceleration, and t is the time in seconds. If we use 32 ft. per second as the constant of acceleration, the distance a body falls in 1 second is $s = \frac{1}{2} \times 32 \times 1^2 = 16$ ft.; the distance it falls in 2 seconds is $s = \frac{1}{2} \times 32 \times 2^2 = 64$ ft.

Falling Bodies

Method. Let the students go out-of-doors and measure from the ground a distance of 16 feet up the side of the building to a window or a balcony. Let one student hold his hand at this height and let pebbles fall one at a time at a given signal. Let another student use a watch with well-marked seconds and announce at the end of successive seconds, "one, two, three, go, one, two." At the word "go" let the first student drop a pebble and let both notice whether the pebble strikes the ground in one second. Make a number of trials.

Does the body fall 16 feet in one second?

Let the first student hold weights of 1 and 2 lb. side by side and let them fall. Does the velocity depend upon the weight?

Measure up the side of the building 36 feet and repeat the experiments. Does the body fall 36 feet in $1\frac{1}{2}$ seconds?

Measure up the side of the building a distance of 64 feet above the ground and repeat the experiments. Does the body fall 64 feet in 2 seconds? Is the space a body falls from rest proportional to the square of the time?

Drop weights of 1 and 2 lb. from this height.

Does the velocity of fall depend upon the weight?

Projectiles

The velocity of a body thrown vertically upwards decreases 32 feet per second each second it is rising; if then a body is thrown vertically upward and rises for 2 seconds its velocity at the start was $V = gt = 32 \times 2$ or 64 feet per second; if it rose 3 seconds its velocity at the start was $V = gt = 32 \times 3 \doteq 96$ feet per second, and so on.

Let one student at a time throw a stone vertically upward and let a second student take the time in seconds from the instant the stone leaves the hand until it strikes the ground. Half of this is the time in seconds the stone rose. Calculate from this the velocity in feet per second of the stone when it left the hand.

Experiment 49. Laws of the pendulum.

To show that the time of swing of a pendulum is independent of the amplitude, for small amplitudes; and that the time of swing varies as the square root of the length of the pendulum.

Pendulum. Watch.

Method. **Time of swing independent of the amplitude, for small amplitudes.** Make a pendulum about 3 ft. long and start it swinging through an arc of about 6 in. With a watch take the time of 100 swings. Start it swinging through an arc of 1 foot and take the time of 100 swings. Is the time of swing independent of the amplitude?

Time of swing varies with the length. Attach a metal sphere (about 1 in. diam.) to a fine wire and make the length of the pendulum (from the point of support to the center of the bob) exactly $1\frac{1}{2}$ foot. Find the time of 100 swings and calculate the time of one swing.

Set up a pendulum exactly 6 feet long. Find the time of 100 swings and calculate the time of one swing.

The 6 foot pendulum is 4 times as long as the $1\frac{1}{2}$ foot pendulum; is its time of swing $\sqrt{4}$ or 2 times that of the $1\frac{1}{2}$ foot pendulum, that is, does the time of swing vary directly as the square root of the length of the pendulum?

FORM OF REPORT

	100 Swings	1 Swing
Amplitude 6 in., time		
Amplitude 12 in., time		
Pendulum $1\frac{1}{2}$ ft. long, time		
Pendulum 6 ft. long, time		

APPENDIX

TABLE OF DENSITIES

Alcohol ("absolute")	0.8	Lead	11.4
Aluminium	2.65	Limestone	2.6–2.8
Brass	8.5	Marble	2.5–2.8
Cork	0.2	Mercury	13.6
Copper	8.5–8.9	Milk	1.03–1.033
Gasoline	0.68–0.72	Oak wood	0.7–0.9
Glass (Flint)	3.0–5.9	Pine wood	0.5
Glass	2.5–2.7	Platinum	21.5
Granite	2.5–2.9	Sandstone	1.9–2.5
Gold	19.3	Sea water	1.03
Iron	7.1–7.9	Sulphur	2.0
Kerosene	0.80	Vinegar	1.01–1.08

The density of air at 20° C. or 68° F. and at 1 atmosphere pressure (76 cm.) is 1.205 g. per liter or .0012 g. per cc.

Coefficients of Linear Expansion of Solids

Brass	.0000189	Steel	.000011
Copper	.0000167		

Table of Specific Heats

Aluminium	.220	Iron	.110
Brass	.090	Lead	.031
Copper	.094	Mercury	.033

Resistance of Wire per 1000 feet

No. 30 Brown and Sharp Gauge

Copper	German-silver 18% Nickel	Iron (annealed)
105.1 ohms	1892 ohms	909.5 ohms

APPARATUS FOR LYNDE'S LABORATORY COURSE IN PHYSICS OF THE HOUSEHOLD

EXPERIMENT	APPARATUS	APPROXIMATE COST
	MECHANICS	
1.	Yardstick	.25
	Lever support	.50
	Iron weight with ring, 2 lb.	.75
	Iron weights with ring, 1 lb., 2 @ .75	1.50
	Meter stick	.30
2.	Spring balance, 2000 g., 64 oz.	.55
	Block of wood 8″ × 3½″ × 3½″	.30
	Laboratory support, tripod base, leg 12.5 cm.	.50
	Rod 80 cm., 13 mm.	.60
	Clamp, right angle	.45
	Clamp with 15 cm. rod	.35
3.	Single pulleys, 4 @ .20	.80
4.	Gallon to ½ pint, 5 pieces	1.25
	Pail, a cube 6″ × 6″ × 6″	.75
	Balance, lb., with flat platforms, and side beam 0 to 16 oz., 5 weights, 1 lb.	3.75
	or Standard family scale	1.75
5.	Liter measure	.50
	Balance (gram)	12.75
	Weights in holder, 500 to 10 g.	1.65
6.	Pail, 12 quart	.65
	Pails, 3 quart, 4 @ .20	.80
	Overflow pail with spout and handle, 8½″ × 5½″ × 5½″ deep	.75
7.	Aluminium cylinder, with hook	.45
	Graduated cylinder, 100 cc.	.70
8.	Apparatus listed above	
9.	Specific gravity bottle, 50 cc.	1.10
	Hydrometer, universal	1.45
	Hydrometer jar 18″ × 3″	1.10
10.	Barometer tube, ordinary tubing ⅜″ sealed at one end, 120 cm. long	.40

	Same, tubing ¼ in., 100 cm. long	.25
	Evaporating dish, 3 in. dia.	.15
	Evaporating dish, 4 in. dia.	.30
	Mercury, 2 lb. @ 1.50	3.00
	Funnels, 1½″ dia., 2 @ .20	.40
	Siphon, 2 pieces glass tubing ⅜″, 30″ long, @ .10	.20
	Heavy rubber tubing to fit glass tubes above, 18″	.30
11.	Boyle's Law tubes unfilled	.30
	Sealing wax, 1 stick	.15

HEAT

12.	Tumblers, 2 @ .10	.20
	Thermometers (– 10° to 110° C. and – 17° to 220° F.), 2 @ 1.25	2.50
	Boiler hypsometer	3.00
	or Boiler (sirup can, 1 gal.)	.25
	Stopper, 2 hole, glass tube elbow, to fit sirup can	.15
	Tripod, 5 in.	.25
	Bunsen burner	.25
	Rubber tubing, $\frac{3}{16}$″, 2 feet	.20
13.	Expansion apparatus	3.00
14.	Flask, 1000 c.c.	.60
	One hole rubber stoppers, 2, to fit flask above	.10
	Glass elbow, rubber tube 3 in. and clip	.25
15.	Flatiron, about 4 lb.	.30
16.	Cloth strainer	.05
17.	Apparatus listed above	
18.	Calorimeter	2.60
	Lead shot, 2 lb. @ .15	.30
	Small iron nails, 1 lb.	.10
	Aluminium pellets, ½ lb.	.70
	or Sheet lead, ⅛″, ½ sq. foot	.65
	Aluminium weight	1.10
19.	Apparatus listed above	
20.	Water trap	.25

ELECTRICITY AND MAGNETISM

21.	Student's demonstration battery	1.33
	Simple galvanometer	1.25
	Compass	1.60
22.	U magnets, 2 @ .30	.60
	Carton iron filings	.10
	Soft iron bar 6″ × ½″	.10
	Pliers, 4½ in.	.40
	Bar magnet	.20
23.	Pane of glass, 15″ × 15″	.25
	Compass, 10 mm.	.15
	Filings sifter	.10
24.	Dry cells, 2 @ .30	.60
	Soft iron horseshoe	.10
25.	Electric bell	.45
	Push button	.10
	Telegraph sounder and key, 2	5.50
26.	Demonstration motor with electromagnet	3.50
27.	Lead elements, 12.5 × 2 cm., 2 @ .05	.10
28.	Wheatstone bridge	3.00
	Resistance box	7.50
	D'Arsonval galvanometer	3.00
	Contact key	.75
29.	Voltmeter and ammeter on stand	33.00
	Electric immersion heater, 110 volts	3.75
30.	Apparatus listed above	
31.	Apparatus listed above	
32.	Magneto	5.50
	Dynamo, hand power	35.00
	Lamp and receptacle for dynamo	.50
	Induction coil (demonstration)	6.00
	Nails, 5 inch, 4	.10
33.	Motor, $\frac{1}{16}$ h.p.	23.00
	Speed counter	1.10
	Large clamp, 6 in.	.65

Light

34.	Bunsen photometer, student's	1.00
	Kerosene lamp	.25
	Electric light receptacle	.25
	Attaching plug	.40
	#18 Lamp cord, 10 feet	.60
	Carbon lamp 16 c.p., 110 v.	.30
	Tungsten lamp 40 w., 110 v.	.85
35.	Thin mirror 4″ × 4″	.10
	Black pins, 1 paper	.05
	Protractor, brass, 3½″	.15
	Ruler, 1 foot	.10
36.	Plate glass, parallel sides	.20
	Drawing compass	.15
37.	Lens holders, 2 @ .10	.20
	Lens, 8 in. focus	.30
	Screen supports, 2 @ .10	.20
	Screens, 2 @ .05	.10
	Wire gauze screen	.10
38.	Apparatus listed above	
39.	Linen tester	.35
40.	Apparatus listed above	
41.	Glass prism	1.10

Sound

42.	Revolvers, 2 @ 3.00	6.00
	Stop watches, 2 @ 7.50	15.00
	Boxes blank cartridges, 2 @ .50	1.00
43.	Vibratograph	3.60
	Tuning fork for above	1.35
	Extra plates, 3 @ .10	.30
	Whiting and sponge	.15
44.	Tuning fork 512	.09
	Resonance tube, 20″ × 1¼″	.50
	Rubber bands, 6	.05
45.	Simple sonometer	1.35
	Sonometer wires, set of 4	.25

Advanced Mechanics

46.	Small clamps, 3 @ .25	.75
	Spring balances, 2000 g., 64 oz., 2 at .55	1.10
47.	Apparatus listed above	
48.	Apparatus listed above	
49.	Pendulum bobs, 1 in., 2	.20

General Supplies

Sulphuric acid, 1 lb.	.35
Table salt, 3 lb. bag	.15
Potassium hydroxide sticks, 1 lb.	1.25
Copper sulphate, 3 lb.	.90
Kerosene, 1 gal.	.15
Whiting, 4 oz.	.10
Candles, 5 in. long, 1 doz.	.20
Fish line, 1 card, 25 yards, best	.20
Linen thread, spool	.15
Wire #22 c.c. copper, 1 lb.	1.30
Wire #30 bare G. S., 4 oz.	.60
Wire #30 bare iron, 4 oz.	.25
Sewing needles, 1½ in., 1 package	.10

APPARATUS FOR STUDENT'S PRIVATE LABORATORY

APPARATUS	APPROXIMATE COST
Mechanics	
Laboratory support tripod, leg 12.5	.50
Rod, 80 cm., 13 mm.	.60
Clamp with 15 cm. rod	.35
Clamp, right angle	.45
Yard stick	.25
Meter stick	.30
Single pulleys, 4 @ .20	.80
Overflow pail, 8½″ × 5½″ × 5½″ deep	.75
Pail, 3 quart	.15
Spring balance, 2000 g., 64 oz.	.55
Barometer tube complete with cup and pipette	.50

Siphon, 2 pieces glass tubing $\frac{3}{8}''$ × 30″	.20
Rubber tubing to fit glass tubes above, $1\frac{1}{2}$ ft.	.30
Boyle's Law tube unfilled	.30
Mercury, $\frac{3}{4}$ lb.	2.25
Sealing wax, 1 stick	.15

Heat

Pails, 3 quart, 3 @ .15	.45
Thermometer C. and F. (− 10° to 110° C. and − 17° to 220° F.)	1.25
Thermometer, common tin back, 10° to 220° F.	.25
Boiler, 1 gal. sirup can	.25
Stopper, rubber, 1 one-hole, 1 two-hole to fit boiler	.10
Glass tube elbow	.05
Tumbler	.10
Tripod, 5 in.	.25
Bunsen burner	.25
Rubber tubing, $\frac{3}{16}$ in., 3 feet	.25
Flask, 1000 c.c. capacity	.60
Rubber stopper, one-hole to fit flask	.05
Pinchcock	.10

Electricity and Magnetism

Demonstration cell complete	1.35
Lead elements, 2 extra	.10
Simple galvanometer	1.25
Compass, 16 mm.	.20
U magnets, 2 @ 30	.60
Bar magnet	.20
Carton iron filings	.10
Soft iron bar, 6″ × $\frac{1}{2}''$	.10
Soft iron horseshoe core	.10
Dry cells, 2	.60
Pane of glass, 15″ × 15″	.25
Electric bell	.45
Push button	.10

Telegraph sounder and key	2.75
Demonstration motor complete	3.50
Miniature lamp, $2\frac{1}{2}$ v.	.30
Receptacle	.15

Light and Sound

Thin mirror, 4″ × 4″	.10
Black pins, glass heads	.05
Plate glass, parallel sides	.20
Protractor	.15
Optical bench support blocks	.15
Lens support	.10
Screen supports, 2 @ .10	.20
Bunsen screen	.15
Wire gauze screen	.10
Candle holder	.10
Candles, 1 lb.	.20
Lens, 8 in. focus	.30
Linen tester	.35
Screen	.05
Prism	1.10
Sonometer wires, set of 4	.25
Tuning fork A	.15
Tuning fork C	.15

Advanced Mechanics

Pendulum bob, 1 in.	.10

Supplies

Sulphuric acid, 1 oz.	.35
Potassium hydroxide sticks, 1 oz.	.20
Copper sulphate, 8 oz.	.15
Copper wire c.c. #22, 4 oz.	.40
Sewing needles, $1\frac{1}{2}$″, 1 package	.10

Firms

The apparatus for Lynde's Laboratory Course in Physics of the Household can be purchased from the following firms:

United States

Central Scientific Co., 412 Orleans St., Chicago, Ill.
Chicago Apparatus Co., 32 South Clinton St., Chicago, Ill.
Wm. Gaertner & Co., 5345 Lake Park Ave., Chicago, Ill.
L. E. Knott Apparatus Co., Boston, Mass.
Kny Sheerer Co., 225 Fourth Ave., New York, N.Y.
Standard Scientific Co., 147 Waverly Place, New York, N.Y.
C. H. Stoelting & Co., 31 Randolph St., Chicago, Ill.

Canada

George M. Hendry & Co., Ltd., 215 Victoria St., Toronto, Ont.
McKay School Equipment Co., Ltd., 615 Yonge St., Toronto, Ont.
Toronto School Supply Co., Ltd., 210 Victoria St., Toronto, Ont.

Great Britain

Baird and Tatlock, Ltd., Hatton Garden, London, England.
W. & J. George, Ltd., 157 Great Charles St., Birmingham, Eng.
Philip Harris & Co., Ltd., Edmund St., Birmingham, Eng.

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